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47-FT Motor Lifeboat Tactical Maneuvering Reverification Testing

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16. Abstract

Reverification testing was performed on a preproduction 47-FT Motor Lifeboat to obtain an updated view of maneuvering and control performance. Standard vessel test procedures were employed. The testing was done on the CG-47201 which was considered nearest in configuration to the production run 47-FT Motor Lifeboats scheduled for delivery in 1997. The test results were compared to the performance on the prototype CG-47200 in 1991 and to data collected on the CG-47201 after changeout to DDEC engines in 1994.

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METRIC CONVERSION FACTORS

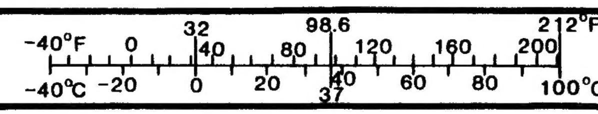
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

Recent alterations to the 47-FT Motor Lifeboat (MLB) baseline design, including the installation of Detroit Diesel Electronically Controlled (DDEC) engine systems, necessitated the need for maneuvering characteristics reverification. It is anticipated that these test results will be indicative of the performance of the production MLB characteristics. Maneuvering and control characteristics were measured and compared to 1991 Developmental Test & Evaluation (DT&E) prototype testing and 1994 DDEC preproduction MLB testing.

The Research & Development Center (R&DC) Test Team conducted trials on the 47201 preproduction MLB located in Cape May, New Jersey in September 1995. The sponsor of these tests was the Search & Rescue Division (G-NRS) of the Office of Navigation Safety & Waterways Services (G-N) located at Coast Guard Headquarters. The testing conducted on the 47201 represents three days of trials and does not duplicate the comprehensive test & evaluations (T&E) conducted on the prototype 47200 MLB in Reference (1). It does, however, provide an updated view of the present MLB performance after growth pains associated with replacement engines and other implemented engineering change proposals to improve the 47-FT MLB design.

The normal outfit weight of the 47201 preproduction MLB was determined to be 41,367 lbs. with a longitudinal center of gravity of 16.6 feet forward of the aft perpendicular. This is 1,134 lbs. more than the normal outfit weight of the prototype MLB measured in 1991. The turning performance between the preproduction and prototype MLBs are comparable, although, turning performance of the preproduction MLB is slightly better. Additional turning data were collected to develop a comprehensive family of turning maneuver data. The inboard engine, in a turn, consistently stalled in split-throttle maneuvers. This poses a potentially dangerous situation if the coxswain reflexively applies this maneuver and an engine stalls in a rescue scenario or emergency maneuver to avoid breaking waves. Acceleration and crash-back deceleration response of the 47201 preproduction MLB is very good. The preproduction MLB has retained good directional stability as evident in the spiral and pullout maneuvers conducted. The zig zag maneuver trials demonstrated reduced ability to rapidly change course and a decrease in countermaneuverability compared to the 47200 prototype results. The preproduction MLB has retained the good speed-trim characteristics demonstrated in the prototype. No dynamic instabilities were present or observed in the trials. The reduction in top speed from 27.1 knots for the prototype to 24 knots for the preproduction MLB reduces the likelihood of dynamic instabilities but continued in-service monitoring is needed if future MLBs are made to go faster. Speed-power trial results are consistent with 1994 DDEC testing results. In general, the noise levels between the prototype and preproduction MLBs are comparable with the exception of high noise levels commented on by the crew and documented in the

1400 to 1500 RPM range. The high noise in this range may be related to the new mufflers which did not have lagging on at the time of this testing in combination with the increased engine load around hump speed. The new location of the exhaust ports, i.e., increased diesel fumes, and increased noise may be cause for concern in terms of crew fatigue in long cases such as in towing missions.

ACKNOWLEDGMENTS

Appreciation is expressed to Station Cape May and the sponsor in Search & Rescue (G-NRS-2). Appreciation is also expressed to CDR Timpe of the R&D Center's Marine Engineering Branch for his technical review and to ETCS Brion for his assistance as part of the test team.

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1 Background

1.1 The 47-FT Motor Lifeboat

The 47-FT Motor Lifeboat (MLB) was developed by the U.S. Coast Guard and Textron Marine & Land Systems (TM&LS) and represents the newest Coast Guard MLB acquisition. The 47-FT MLB is a replacement for the 30 year old 44-FT MLB. The MLB is designed as a surf boat with self righting and self bailing capabilities in severe weather and sea conditions. The Coast Guard may procure as many as a hundred of these craft to serve as the premier small boat station search and rescue MLB. Prior to full-scale production, five preproduction MLBs (designated 47201 through 47205) had undergone an Operational Test & Evaluation (OT&E) to evaluate their effectiveness and suitability as replacements. These boats were placed in different geographic locations to obtain exposure to different operating environments. A contract has been issued to TM&LS for the fabrication of 20 production MLBs with deliveries expected to begin in 1997.

1.2 Technical Characteristics Verification of the Prototype 47 FT MLB

Initial technical verification testing was performed on the prototype 47-FT MLB (47200) in Reference (1). Extensive testing was performed in the original DT&E of the 47-FT MLB prototype. The R&D Center conducted a variety of technical tests including seakeeping, maneuvering, speed-power, endurance, structural loading, etc. The prototype performed exceedingly well in most of the technical areas tested. However, maneuvering problems were identified with the original design of employing large canted rudders which resulted in some unpredictable behavior in high speed turns and broaching in following seas. Twenty one different skeg and rudder configurations were tested during the DT&E to determine the prototype configuration with the optimum calm and rough water performance characteristics.

1.3 47-FT DDEC Preproduction MLB Testing

The original propulsion system of the prototype and preproduction MLBs consisted of Detroit Diesel 6V-92 TA engines with a 2:1 reduction gear and 28” diameter by 33” pitch propellers. Towards the end of the OT&E evaluation period, the engines began failing prematurely and therefore did not meet the original maintenance philosophy of 5000 to 6000 hours between overhauls. The Detroit Diesel 6V-92 DDEC (Detroit Diesel Electronically Controlled) engines were adopted as the new propulsion system for the MLBs to improve service life and performance. The Coast Guard replaced the 47201 engines with a DDEC propulsion system on 26 October 1994. Testing was performed in 1994 on the 47201 preproduction MLB with replacement engines, Reference (2). The emphasis of the tests in Reference (2) was on engine performance and not on vessel maneuverability.

2 Introduction

2.1 Sponsor Objectives

Presently, the only 47-FT MLB maneuvering information available is from Developmental Testing & Evaluation (DT&E) of the 47200 prototype MLB, conducted in 1990. Recent alterations to the 47-FT MLB baseline, including installation of Detroit Diesel Electronically Controlled (DDEC) 6V92 engine systems and changes to the propeller configuration, necessitated the need for reverification of the boat's maneuvering characteristics. The sponsor of the reverification testing is the Coast Guard's Search & Rescue Division (G-NRS) of the Office of Navigation Safety and Waterways Services (G-N). The objectives of the reverification testing were:

- Measure and document the maneuvering and control characteristics of the 47201 by employing standard vessel test procedures in Reference (3).
- Quantify maneuvering differences between performance measured on the 47200 during initial verification testing and the preproduction MLB (47201) nearest in configuration to the production MLBs scheduled to begin being delivered in March 1997.
- Translate test results, wherever possible, into descriptions of maneuvering performance that can be integrated into an operators handbook.

2.2 Overview of Maneuvering Tests

The focus of these tests are on maneuverability and control tests identical to the 47200 DT&E tests discussed in Reference (1). Table 1 reflects the original verification testing that was done in 1990 and identifies test items that were conducted again in 1994. The bold items reflect reverification test items. Italicized items reflect testing documented in Reference (2).

Table 1 List of 47-FT MLB DT&E Tests

Test TC-1	Principal Characteristics
Test TC-2	Photographic Documentation
Test TC-3	Video Documentation
Test TC-4	*Speed vs. Power*
Test TC-5	*Trim vs. Speed*
Test TC-6	Righting Arm vs. Heel Angle
Test TC-7	*Bollard Pull*
Test TC-8	**Minimum Turning Radius**
Test TC-9	**Acceleration/Deceleration**
Test TC-10	Sea Height vs. Maximum Speed

Test TC-11 *Fuel Consumption vs. Speed*
Test TC-12 *Range vs. Speed*
Test TC-13 **Maneuverability (Spiral Test)**
Test TC-14 **Maneuverability (Zig Zag Test)**
Test TC-15 Motion in Waves

Additional performance information was collected in conjunction with the minimum required maneuvering tests outlined.

The reverification testing was conducted from 22 to 27 September in 1995. On 22 September, the 47201 was weighed to determine a normal outfit condition. The R&DC Test Team installed the Tacman4 GPS (described in 2.3), motions package, and tape recorders. Because of difficulties encountered with the installation of strain gauges and horsepower meter on the port propeller shaft, these tests were conducted with torque, horsepower, and RPM measurements from the starboard shaft only.

On 23 September, a 10 knot spiral maneuver was conducted with the 47201 at a test weight of 42,280 lbs.. Prior to the trial a few straight runs at different speeds were conducted to determine the neutral rudder position. The neutral rudder position was determined to be 2 degrees to port. Weather conditions were not optimal. Strong Northeast wind gusts and 2 to 3 foot seas made it difficult to turn the boat at small rudder angles. On 24 September, a 23 knot spiral and zig zag trials were performed with a boat weight of 41,890 lbs.. The weather conditions had improved only slightly over that of the previous day. The rudder angle indicators on the flying bridge were not operational and zig zag steering maneuvers had to be run from the enclosed bridge in order to view the indicator.

On 25 September, tactical turning maneuvers, accelerations, and deceleration's were conducted. The accelerations and deceleration's were performed at a trial weight of 41,151 lbs.. The turning maneuvers were performed at a trial weight of 41,290 lbs..

Up until 26 September, the 47201 had a new 5-bladed propeller design attached. On 26 September the Group Cape May Boat Maintenance Facility (BMF) hauled out the 47201 to changeout propellers. A decision was made by the sponsor of this testing to go with the original 4-bladed propellers for the remaining reverification tests since this configuration more closely reflected the production run MLBs and because the 5-bladed propeller had slightly reduced the top speed performance of the 47-FT MLB.

On 26 September, power-speed, zig zag, split throttle, tactical turning maneuvers, and noise measurements were made at a trial weight of 41,438 lbs.. On 27 September, 10 knot and 20 knot spirals, pullout maneuvers, additional turning circle maneuvers, split throttle, and more noise measurements were performed at a test weight of 42,138 lbs. (note that the top speeds were not taken from 27 September trials). As a result of the decision to use the 4-bladed propellers, most of the data reduced were for testing performed on 26 and 27 September only. All of the analysis and data in this report reflect the boat with the 4-

bladed propellers attached. Analysis of the test data with the 5-bladed propellers was not performed.

2.3 Overview of Test Equipment

All of the reverification sensor test data was recorded on Digital Audio Tape (DAT) Instrumentation recorders during the maneuvering tests. Some information was manually recorded by the crew and R&DC Test Team from the Detroit Diesel Electronic Control System (DDEC) instrumentation displays.

A Humphrey motions package installed near the MLB's center of gravity in the Survivor's Compartment, and a rudder angle indicator were used to measure all of the motion information. Turning circles and position data were collected using an Ashtech GPS receiver and Tacman4 (Tactical Maneuvering) software program on a Compaq portable computer. The Tacman4 program records ship position during maneuvering and determines ship speed, advance, transfer, acceleration, deceleration and other characteristics listed in this report. Sound level measurements were collected using a portable sound level meter.

The following equipment was installed during the testing at Cape May, NJ.

o TRIPLITE Model PV-1000 FC/24, 24 VDC to 115VAC 1000 Watt Inverter

o BRUEL & KJAER Model BZ100 Precision Sound Level Meter

o WIRELESS DATA CORP, (Formerly ACUREX) Model 1642 Horsepower Meter
W/ shaft mounted collars and strain gauges

o HUMPHREY Model H-1 Motion Package, 6 Degrees of Freedom (DOF)

o MAGNETEK Model PSA-40A 5K(A179) Linear Motion Transducer

o ASHTECH Model XII Global Positioning System (GPS) Receiver

o TEAC Model RD-200T 16 channel Digital PCM Data Recorder

o COMPAQ Portable Computer

o TACMAN4 GPS Data Acquisition Software

o Boat Weighing System
- 2 - LEBOW Model 3157 Load Cells
- 2 - BLH Model UG31C Load Cells
- 1 - BLH Model 450A Transducer Indicator
- 2 - MICROMEASUREMENTS Type 2310 Signal Conditioning Amplifier

The following additional equipment was used during data reduction.

o TEAC Model RD-101TD Digital PCM Data Recorder

o FLUKE Model 97 Scopemeter

o TEAC Quick VU II Software

o TRIMETRIX Axum Technical Graphics and Data Analysis Software

3 Test Results

3.1 Boat Weighing

On 22 September, the 47201 was measured twice using the BMF travel hoist. The boat was weighed in the full load normal outfit condition (without crew). The fuel tanks were filled to 95% capacity (375 gallons). The measurements were performed with four 20K and 10K lbs. load cells and calibrated meters. The readout meters were zeroed out with the hoist straps. The load cell angles relative to vertical were measured so that a true vertical scale weight reading was obtained from each load cell. Table 2 presents the results of the two weighings.

Table 2 - 47201 Weight Test Summary

Run No.	Scale Weight	Longitudinal Center of Gravity (LCG) fwd. AP
1	40,710 lb.	16.62 ft
2	40,583 lb.	16.57 ft
Average	40,647 lb.	16.59 ft

The results were an average hoist weight of 40,647 lbs.. This was within the 1% accuracy of the R&D Center load cells. The hoisting weight of the 47201 during the DDEC testing in Reference (2) was 40,350 lbs.. This represents a weight growth of about 300 lbs.. A normal outfit condition was calculated as follows:

4 crew X 180 lbs.	720 lb.
Hoist Weight	40,647 lb.
Normal Outfit	41,367 lb.

The prototype normal outfit weight reported from in Reference (1) was 40,233 lbs. (25 gallons of fuel subtracted to reflect 95% capacity). The normal outfit weight determined for the 47201 was also the target test weight for the reverification trials. It was important to be in the vicinity of the target weight in speed critical evaluations. The amount of fuel on-board was adjusted to compensate for the R&D Center instrumentation (306 lbs.) and test personnel for the speed critical trials.

The locations of the hoist straps were recorded with respect to the Aft Perpendicular (AP) of the 47201 in order to determine its Longitudinal Center of Gravity (LCG). It was assumed that the AP coincides with Station 10 on the 47-FT MLB drawing No. 47AMLB-801-001. The LCGs calculated are presented in Table 2. The LCG calculated for the 47201 during the DDEC testing in Reference (2) was 16.5 feet.

3.2 Minimum Turning Radius

Almost all ship maneuvers involve some degree of turning. Therefore, quantifying a vessel's turning maneuverability is important. The turning path of a vessel is characterized by four numerical measures: 1) advance, 2) transfer, 3) tactical diameter, and 4) steady turning diameter. Figure 1 illustrates these measures.

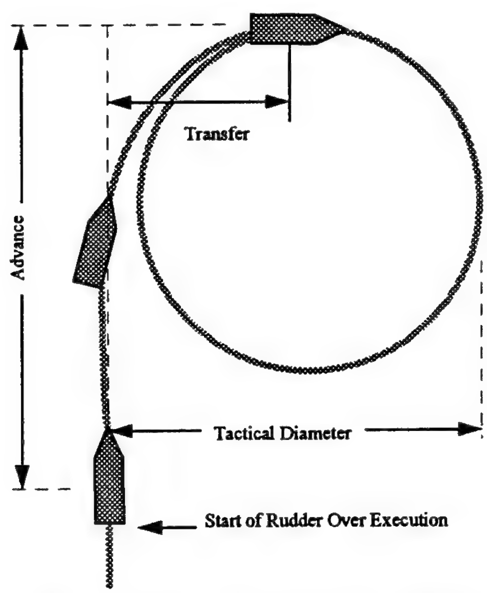


Figure 1 Tactical Turning Maneuver

The advance is the distance from the point of execution when the rudder is quickly placed over to the desired setting to the point when the boat has turned 90 degrees. The transfer is the distance from the original approach course to the boat's center when it has turned 90 degrees. The tactical diameter is the distance from the original approach course to the point where the boat has turned 180 degrees. The steady turning diameter is different from the tactical diameter. The tactical diameter includes the initial transient part of the maneuver whereas the steady turning diameter reflects the footprint of the steady-state part of the maneuver only.

The trials were conducted in a calm area of water. Each run was started with the boat on a straight approach with a fixed throttle, i.e., engine RPM held constant. At the turning point, the rudder was rapidly moved to a specified angle and held there until the boat changed a course of 720 degrees. The track of the boat was measured by the Tacman4

software. Corrections were made for set and drift using the Tacman4 software. Six degrees of freedom of motion measured by the Humphreys motions package were recorded to a digital tape recorder.

Turning circle measurements were conducted on the prototype 47-FT MLB in Reference (1). Turning maneuvers were conducted at 10 knots, 20 knots, and at maximum speed. A maximum speed comparison could not be made between the prototype and preproduction boat because of the disparity of maximum speeds. However, the comparisons that could be made are presented in Table 3. The 10 and 20 knot runs of the 47200 and 47201 were comparable. The 47201 does appear to have some improved turning performance compared to the 47200. Both turning radii and tactical diameters are slightly smaller on the preproduction MLB. The differences may be due to the slight difference in configurations between the MLBs tested. The results reported in Reference (1) reflect the 47200 with the 1.9 ft^2 vertical rudders without strut extensions. The preproduction MLBs. have shaft strut extensions to protect the propellers and rudder from potential damage in case of accidental grounding. A family of turning circle maneuvers for the 47201 preproduction MLB are presented in Figures 2 through 9. The maneuvers are all plotted to the same scale. This provides a physical impression of the footprint size associated with specific turning maneuvers. Table 4 presents the results of Figures 2 through 9 and includes additional detail on the advance, transfer, and speed loss associated with these turn maneuvers.

Table 3 Comparison of Prototype and Preproduction MLB Turning Performance

47200 Prototype				47201 Preproduction			
Speed	Time to Turn 360	Turning Radius/ Tact. Dia.	Rudder	Speed	Time to Turn 360	Turning Rad./Tact. Dia.	Rudder
10 kts	53 sec	35/71 yd.	30 deg	10 kts	44 sec	33/68 yd.	30 deg
20 kts	43 sec	56/** yd.	30 deg	20 kts	45 sec	49/112 yd.	30 deg
27 kts(max)	44 sec	65/157 yd.	30 deg	**	**	**	**
**	**	**	**	24 kts	44 sec	45/128 yd.	30 deg

** Data Not Collected

Table 4 Preproduction MLB Turning Performance Summary

47201 Turning (Rudder Only) Maneuvering Summary								
Speed	Rudder Position	Time to Turn 90 deg	Time to Turn 180 deg	Time to Turn 360 deg	Tactical Diameter	Advance @ 90 deg	Transfer @ 90 deg	Average Turning Speed
10 kts	20 deg	20 sec	35 sec	62 sec	93 yd.	70 yd.	57 yd.	10 kts
10 kts	30 deg	14 sec	22 sec	44 sec	68 yd.	53 yd.	37 yd.	9 kts
15 kts	20 deg	19 sec	32 sec	58 sec	130 yd.	110 yd.	82 yd.	13 kts
15 kts	30 deg	15 sec	26 sec	47 sec	82 yd.	68 yd.	46 yd.	10 kts
20 kts	20 deg	18 sec	34 sec	61 sec	175 yd.	118 yd.	94 yd.	16 kts
20 kts	30 deg	16 sec	26 sec	45 sec	112 yd.	120 yd.	64 yd.	13 kts
24 kts	30 deg	9 sec	23 sec	44 sec	128 yd.	83 yd.	37 yd.	13 kts

47201 10 KT 20 Degree Port Turning Maneuver

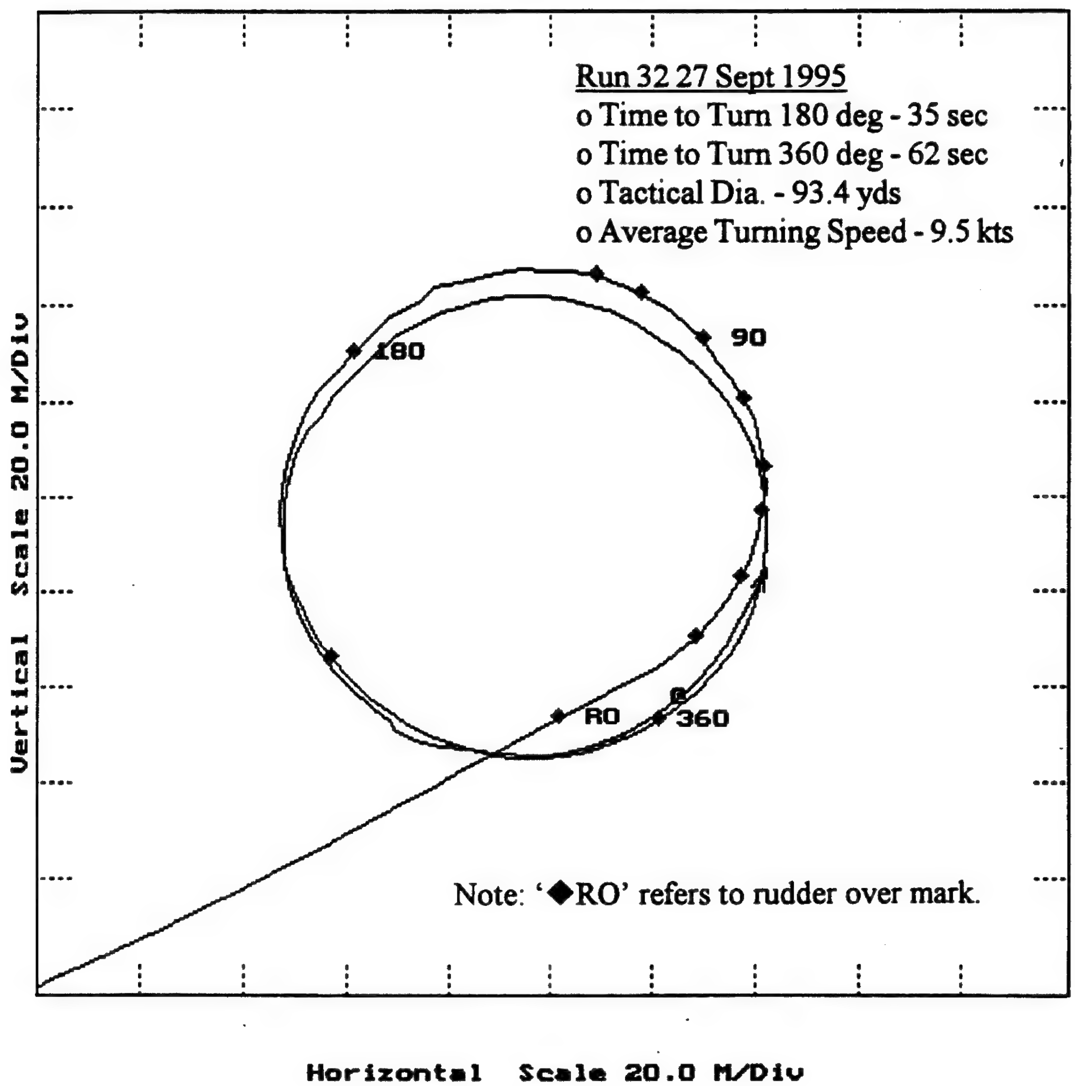


Figure 2. 47201 10 KT 20 Degree Port Turning Maneuver

47201 10 KT Maximum Port Rudder Turning Maneuver

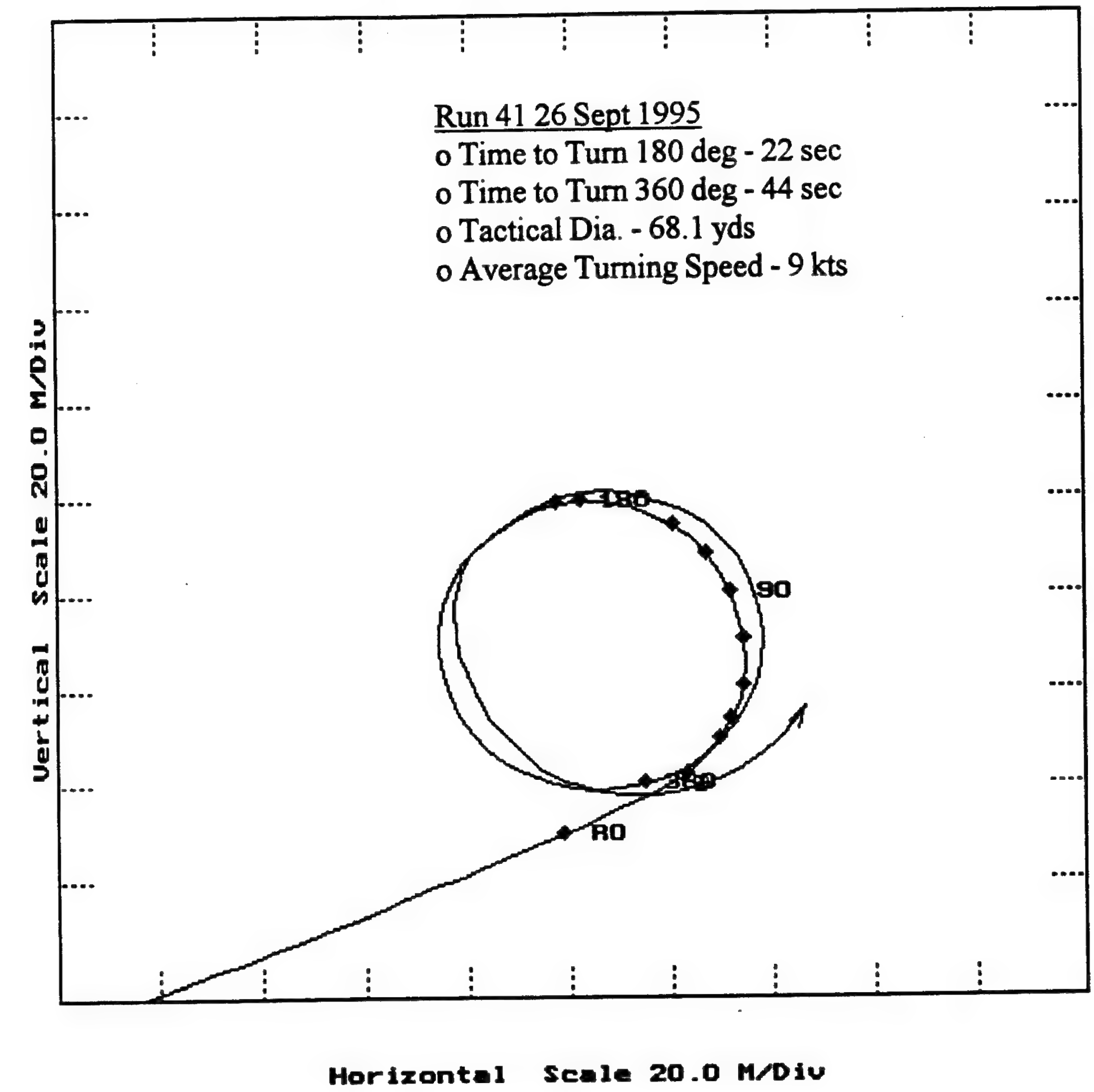


Figure 3. 47201 10 KT Maximum Rudder Port Turning Maneuver

47201 15 KT 20 Degree Port Turning Maneuver

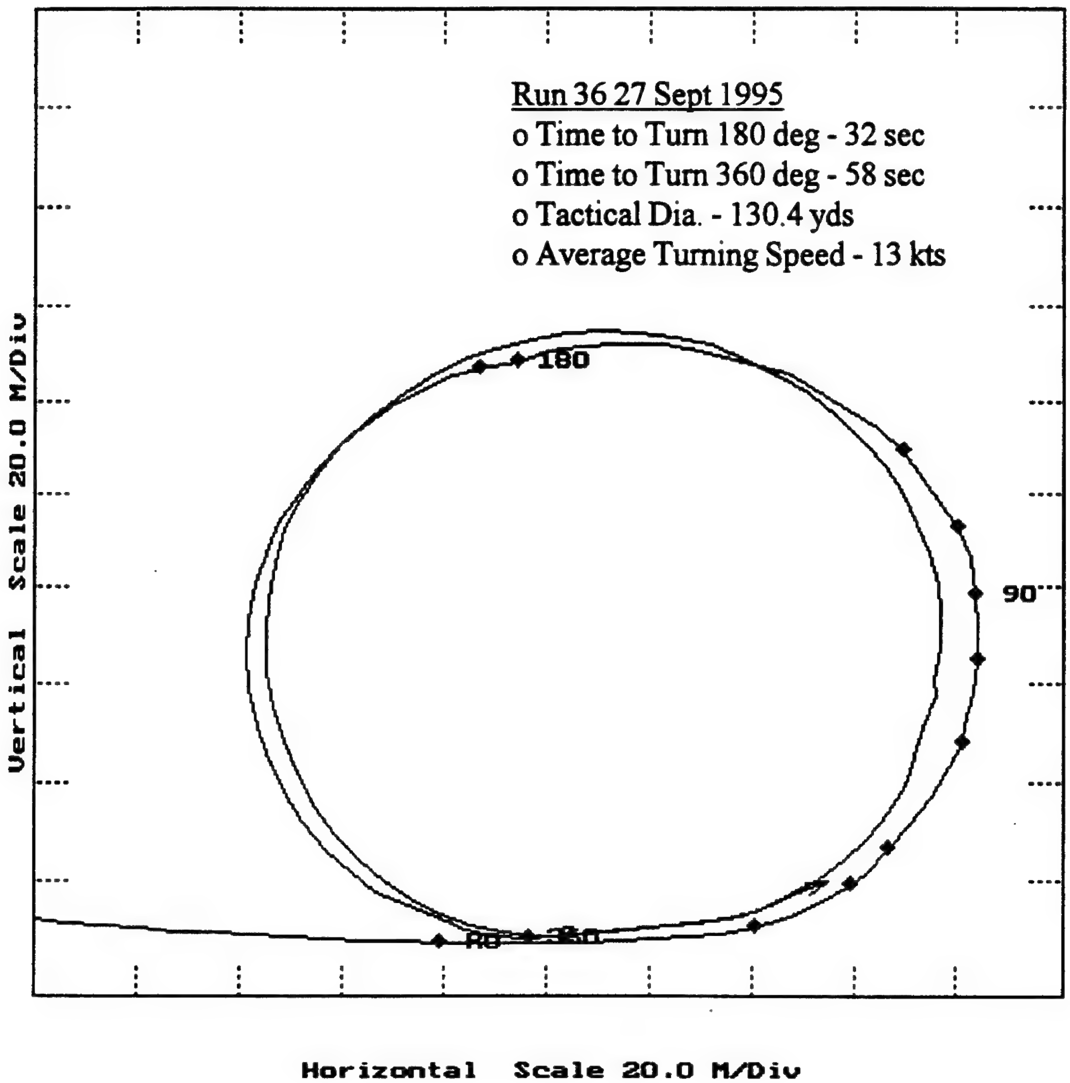


Figure 4. 47201 15 KT 20 Degree Port Turning Maneuver

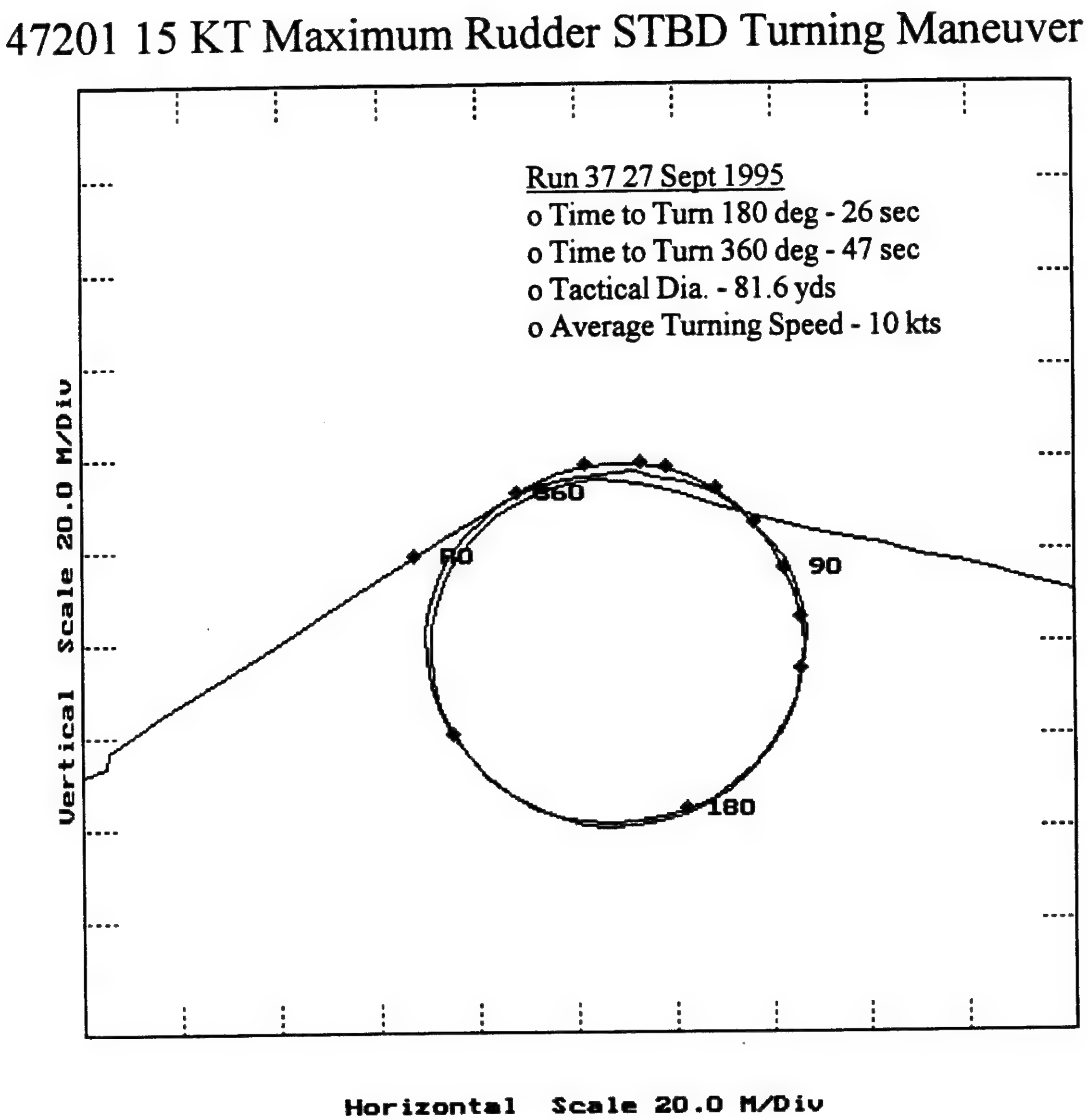


Figure 5. 47201 15 KT Maximum Rudder STBD Turning Maneuver

47201 15 KT Maximum Rudder STBD Turning Maneuver

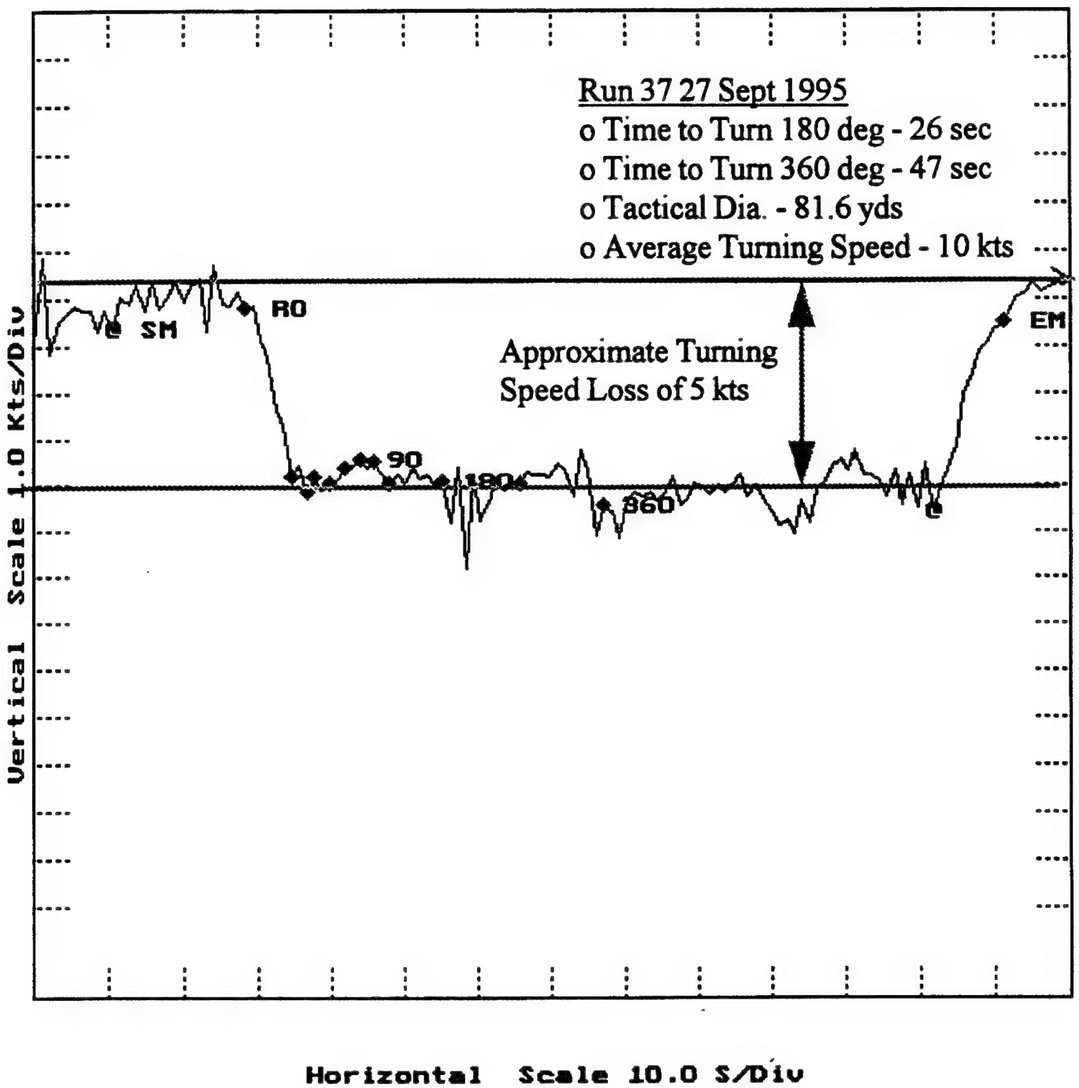


Figure 6. 47201 15 KT Turning Speed Loss

47201 20 KT 20 Degree STBD Turning Maneuver

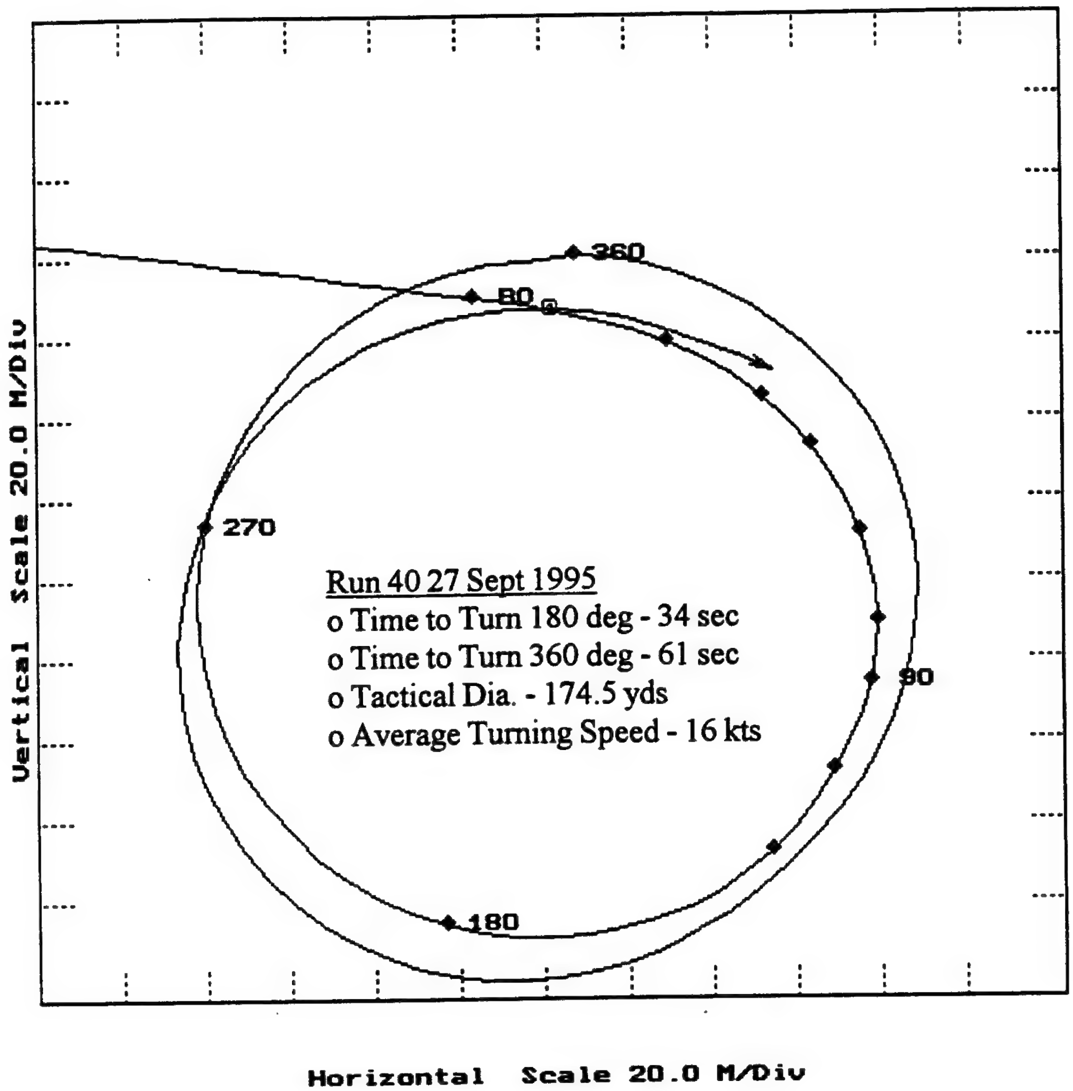


Figure 7. 47201 20 KT 20 Degree STBD Turning Maneuver

47201 20 KT Maximum STBD Rudder Turning Maneuver

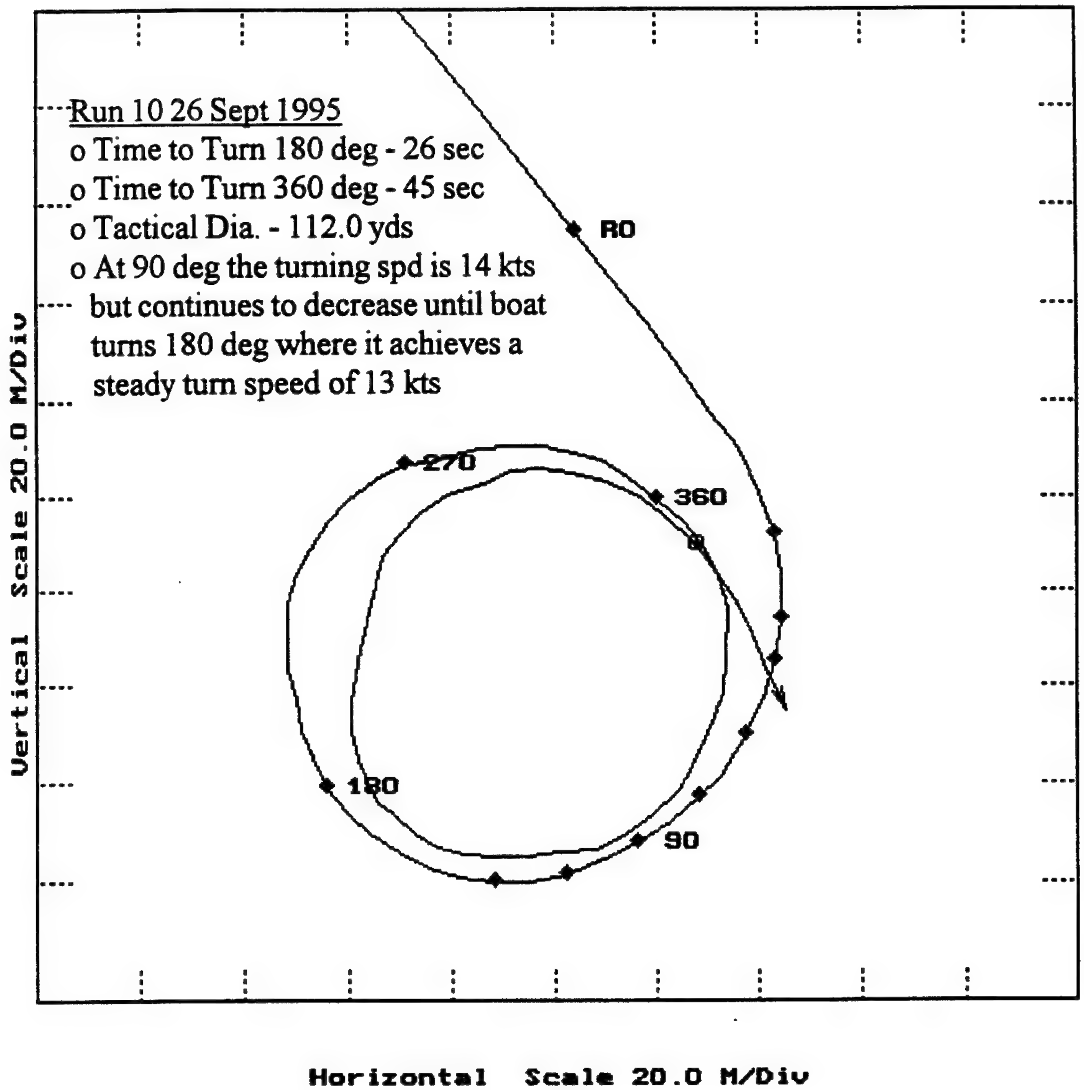


Figure 8. 47201 20 KT Maximum STBD Rudder Turning Maneuver

47201 23 KT Maximum STBD Rudder Turning Maneuver

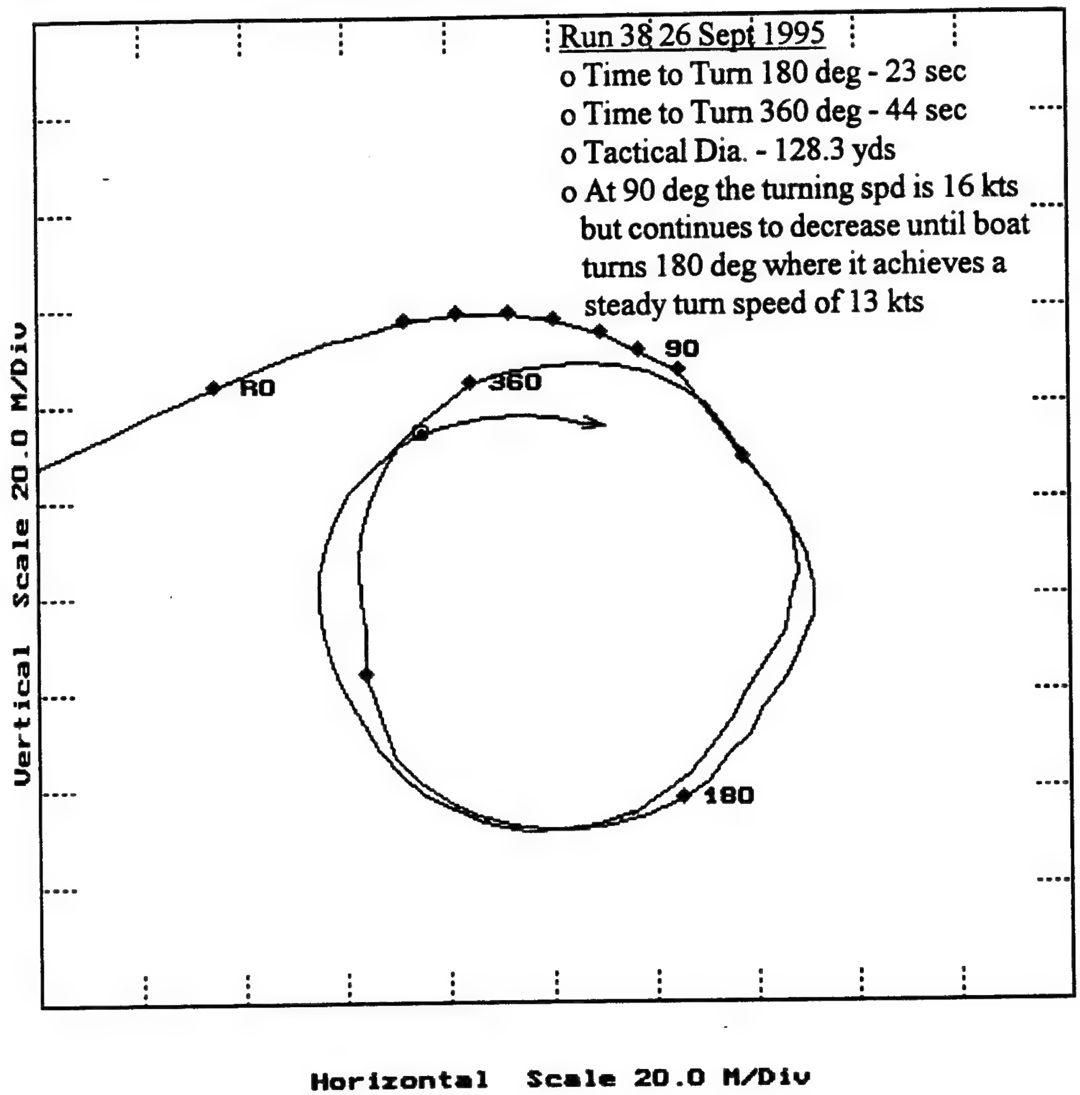


Figure 9. 47201 23 KT Maximum STBD Rudder Turning Maneuver

An initial and intuitive guess as to the relationship between speed and tactical diameter might be that greater initial turning speeds would result in smaller tactical diameters. In fact, the tactical diameters increase with increasing speed for the MLB. The quickest time to turn the 47201 180 degrees in a turn would be either at 10 knots or at maximum speed with the rudder hard over. The 180 degree turning times between maximum and 10 knot speed are probably comparable because of the large tactical diameter and significant speed loss that is paid for in the maximum speed maneuver.

The average turning speeds were extracted from the Tacman4 system. Figure 6 demonstrates a typical velocity plot associated with a turning maneuver. Although some of the velocity plots were not as steady in turning speed, i.e., some sinusoidal behavior in the turn, they generally followed the characteristics of Figure 6. The reduction of speed in a turn for maximum applied rudder for the 47201 can be summarized as follows,

@ 10 knots - 10% reduction
@ 15 knots - 33% reduction
@ 24 knots - 46% reduction

The last series of maneuvering tests on the 47200 were conducted in 1992, in Reference (4). Two configurations were evaluated. The configuration with the 1.9 ft^2 vertical rudders with no strut extensions and no skeg was the optimal configuration selected for combined calm and rough water performance and represents the closest configuration to that of the 47201 in 1995. The testing in Reference (4) was the last series of tests in a systematic study of 21 different skeg and rudder combinations conducted during the DT&E of the prototype. In the turning test comparisons, of Reference (4), particular attention was paid to the heel in the turn because of excessive heel problems associated with past hull appendage configurations. Inclinometers were used in these tests to record the maximum heel and average turning heel. This provided a rough measure of heel, but some errors associated with the effects of lateral accelerations in the turn were to be expected. The heel in the turn data collected in the reverification tests were collected with the gyro-stabilized Humphreys motions package.

Appendix A contains plots of 47201 heel and yaw as a function of time for 10, 20, and 23 knots, i.e., associated with turning maneuvers in Figures 3, 8, and 9, respectively. A mean roll (heel) was determined for the entire turning maneuver for turns in both directions which includes the initial transient part of the turn and steady-state part of the turn. A summary of averaged results are:

10 kts ⇔ 2.1 degrees of heel
20 kts ⇔ 5.6 degrees of heel
23 kts ⇔ 6.6 degrees of heel

The 10 knot data results in Reference (4) had an average steady heel of 2.5 degrees and maximum heel detected of 5 degrees, and the 27 knot data results had an average of 6.4

degrees and a maximum heel detected of 13.8 degrees. The results between the prototype and preproduction MLB are generally consistent. In addition, no excessive heeling in turns or rolls were observed during any of the reverification test maneuvers conducted.

3.3 Split Throttle Maneuver

In a rescue or emergency situation, the coxswain may be required to maneuver the 47-FT MLB using both engines in combination with rudder action. The trial approach was similar to the rudder-alone turning maneuver except that the throttles were split, i.e., the inboard throttle was moved to idle or reverse in a turn. The main purpose of this test was to document the maneuverability advantage that could be gained from using a two propeller MLB. In addition, this maneuver is a good test, like that of a crash-back maneuver, for testing extreme conditions on the propulsion system.

On 26 September, three attempts were made to perform a 20 knot maximum starboard rudder split throttle maneuver. In each case the starboard engine stalled, and the maneuver was aborted. The result was the same (port engine stalled) when the same maneuver was attempted to port. One of the 20 knot maneuvers was captured by the Tacman4 system even though a full two circles could not be performed before the inboard engine stalled. Figures 10 and 11 demonstrate the results of this maneuver. The tactical diameter was determined from user defined marks for an arc defined between locations 'A1' and 'A2' on the boat's track as shown in Figure 10. The 'RO' marks in Figures 10 and 11 represent the time the coxswain initiated the split throttle turn. The 'SM' mark seen on Figure 11 and other figures signifies the general start of a particular maneuver.

Appendix B presents a time history of horsepower, RPM, and shaft torque for this event. Figure B1 demonstrates what happens to the inboard engine in a split throttle maneuver. Note the time frame when the engine RPM quickly goes to zero. It's at this point in time that the inboard engine stalls. Although shaft rotations temporarily stop, they quickly increase because of wind-milling and slowly decrease again as the MLB slows down. Figure B2 demonstrates the results on the outboard engine in a split throttle stall. Shaft torque and RPM decrease but not significantly.

A split throttle maneuver was attempted on 25 September inside Cape May Harbor. The maneuver was conducted at 10 knots. Capturing a full two turning circles to correct for set and drift was not possible. Figures 12 and 13 demonstrate the Tacman4 results from this maneuver. The 47201 demonstrated a footprint tactical diameter of 18 yards with a

47201 20 KT Maximum Split Throttle STBD Turning Maneuver

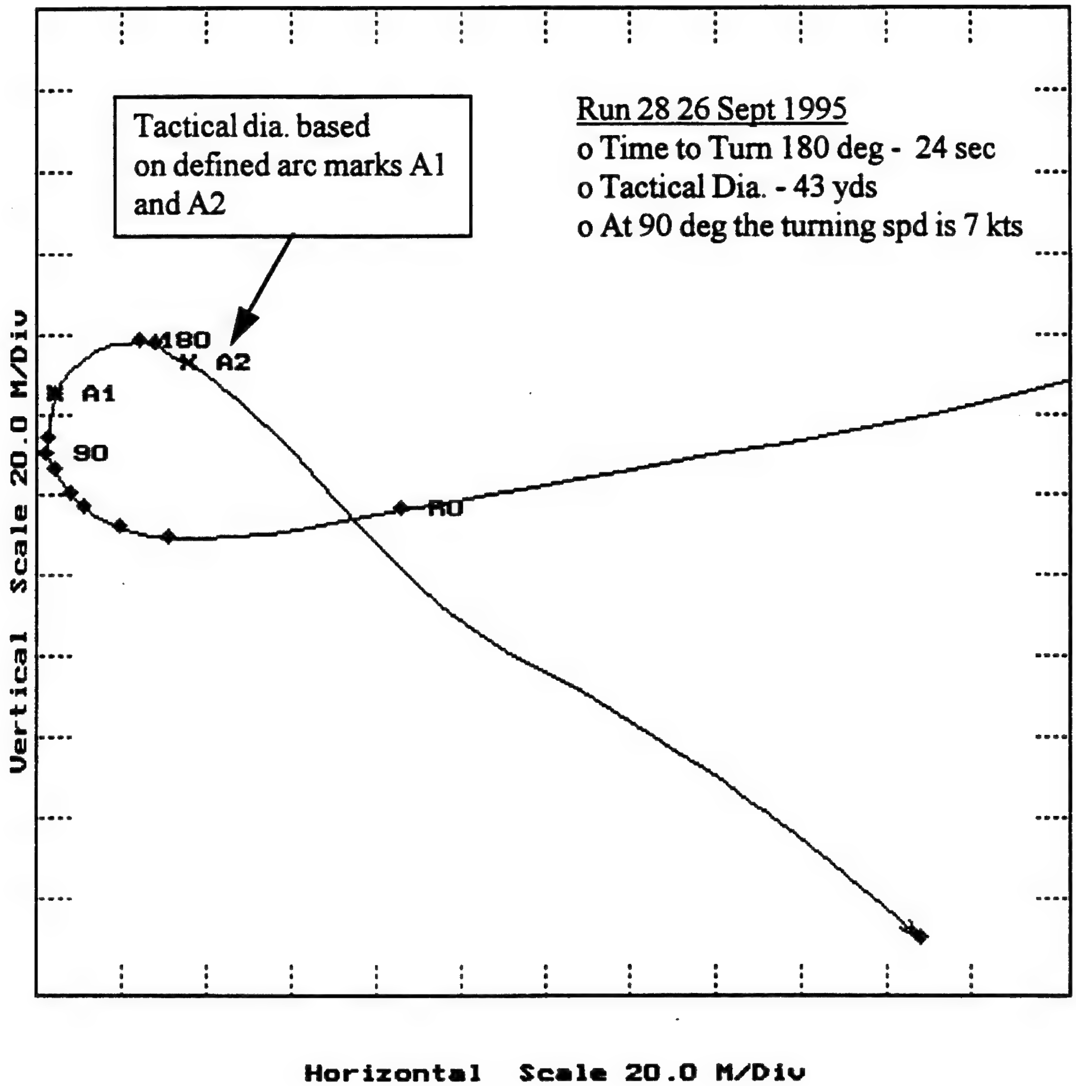
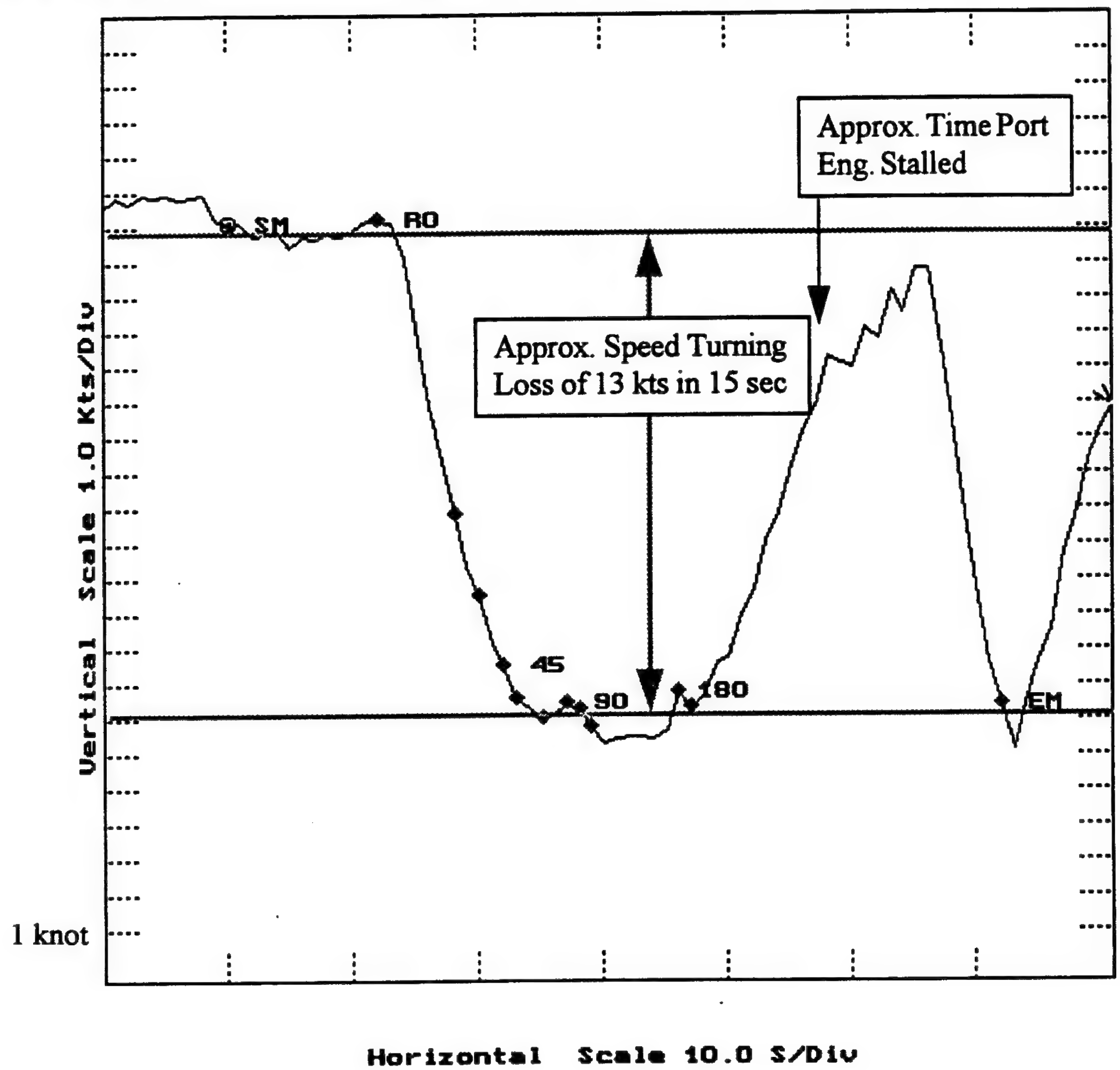


Figure 10. 47201 20 KT Maximum Split Throttle STBD Turning Maneuver

47201 20 KT Maximum Split Throttle STBD Turning Maneuver



Note: '@SM' refers to start of maneuver and '◆EM' refers to end of maneuver.

Figure 11. 47201 20 KT Split Throttle Speed Loss

47201 10 KT Maximum Split Throttle STBD Turning Maneuver

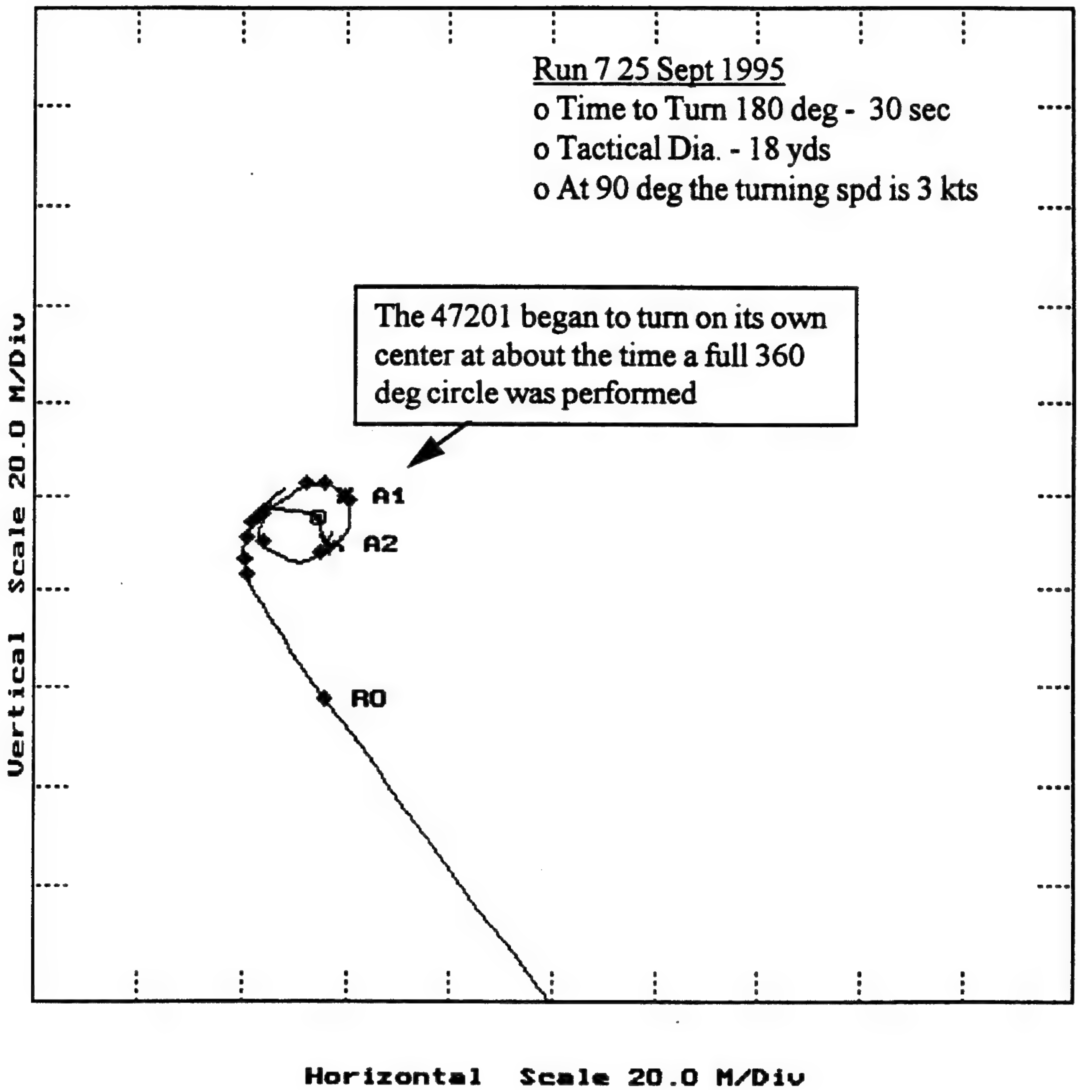


Figure 12. 47201 10 KT Split Throttle STBD Turning Maneuver

47201 10 KT Maximum Split Throttle STBD Turning Maneuver

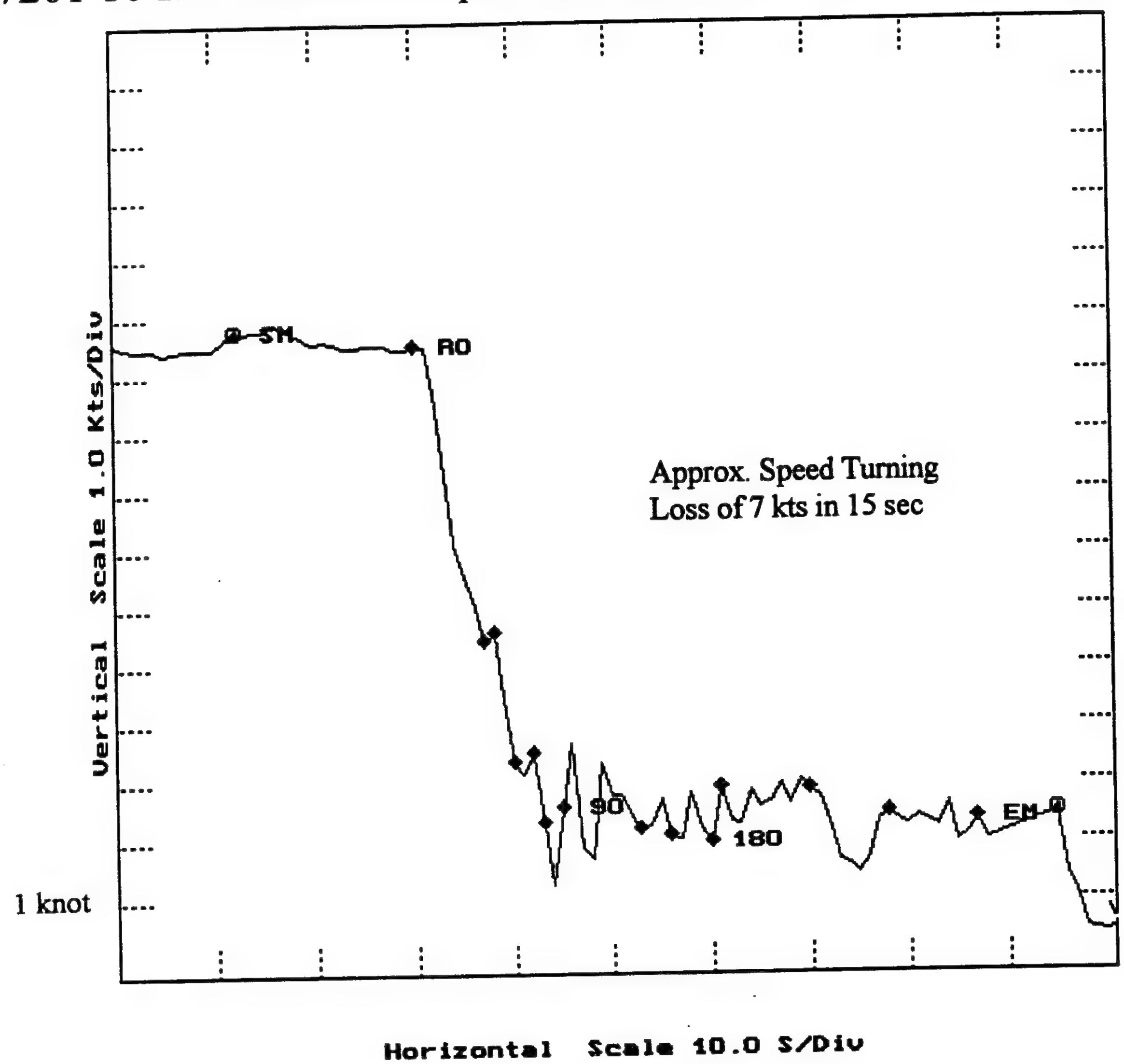


Figure 13. 47201 10 KT Split Throttle Speed Loss

reduction of speed of approximately 7 knots in 15 seconds. In this instance the inboard engine did not fail. However, because of the slow speed, the 47201 began to turn on its own center shortly after completing a full circle. The results of these maneuvers are tabulated in Table 5.

Table 5 Split Throttle Maneuvering Summary

47201 Turning (Split Throttle) Maneuvering Summary							
Speed	Rudder Position	Time to Turn 90 deg	Time to Turn 180 deg	Tactical Diameter	Advance @ 90 deg	Transfer @ 90 deg	Average Turning Speed
10 kts	30 deg	15 sec	30 sec	18 yd.	41 yd.	13.7 yd.	3 kts
20 kts	30 deg	15 sec	24 sec	43 yd.	88 yd.	35 yd.	7 kts

It was thought that the DDEC governor would eliminate the previous problems with splitting throttles on the non-DDEC preproduction boats. Conceptually, the DDEC governor should control the desired speed even as propeller load varies and protect the engine from severe throttling transients. Apparently, the splitting of throttles on the present configuration of the 47201 is no longer a viable option to the coxswain and presents a potentially dangerous condition if reflexively applied in the wrong operational circumstances. Any requirement placed on the coxswain to apply measures to protect the engines from stalling that can't be instinctively carried out in a dangerous or rescue situation is unrealistic.

3.4 Acceleration/Deceleration Maneuver

Acceleration and deceleration maneuvers were conducted on 26 September. Appendix C Figures C-1 through C-4 present the Tacman4 acceleration data. Two sets of runs were conducted. Each set consisted of a trial in the opposite direction to negate the effects of set and drift in determining a top speed, e.g., C-1 and C-3 were performed in on direction and C-2 and C-4 were done in a 180 degree reverse heading. An average top speed of 24 knots can be achieved with the 47201 preproduction MLB. These results were confirmed in speed - power runs on 26 September when a maximum average speed of 24 knots was achieved at 2100 RPM. A time to full speed and distance to full speed was averaged for these trials. The averaged results were:

Acceleration Maneuver:
Time to Full Speed (24 knots) - 40 seconds
Distance to Full Speed (24 knots) - 1106 ft or approx. 0.2 nautical mile

A crash-back maneuver was also conducted with one set of trials. The Tacman4 results are presented in C-5 and C-6. The averaged results for the crash-back maneuver are:

Deceleration (Crash-Back) Maneuver:
Time to dead-in-the-water (DIW) - 9 seconds
Distance to DIW - 132 ft or approx. 3 boat lengths

A slightly faster stop would be achieved with a simultaneous crash-back and rudder-over maneuver. This was not attempted, and therefore it is not known if this might cause the inboard engine to stall as in the split throttle maneuver. It should be noted that one engine did stall in a crash-back maneuver with the 5-bladed propeller attached.

A coasting deceleration maneuver was also conducted by throttling the engines to idle from full-speed ahead. The results are:

Deceleration (Coasting) Maneuver:
Time to DIW - 1 min. 10 sec.
Distance to DIW - 394 ft or approx. 8.4 boat lengths

A coasting maneuver requires nearly 3 times the stopping distance than a crash-stop reversal. The coasting deceleration results are presented in Figures C-7 and C-8 for information.

3.5 Spiral Maneuverability Test

The spiral maneuver trial provides a measure of the stability of the heading control system of a boat. It will reveal hysteresis in control effectiveness and loss of control at extreme rudder angles. This test requires a large operating area.

The trial was initiated by running a straight course at constant RPM. The rudder was moved to 25 degrees starboard and held until the turning rate became steady, usually taking about 2 - 3 minutes. The rudder was moved in small increments of rudder angle starting at 25 degrees to starboard and working towards 25 degrees to port and back again to 25 degrees starboard. The spiral test was conducted at 10 knots and 20 knots.

The results of the spiral test are presented in Figures 14 and 15 and demonstrate that the 47-FT preproduction MLB retains good directional stability. Some hysteresis appears in the 20 knot trial but this is minimal and occurs at small rudder deflections. The results are comparable to the prototype spiral trials detailed in Reference (1).

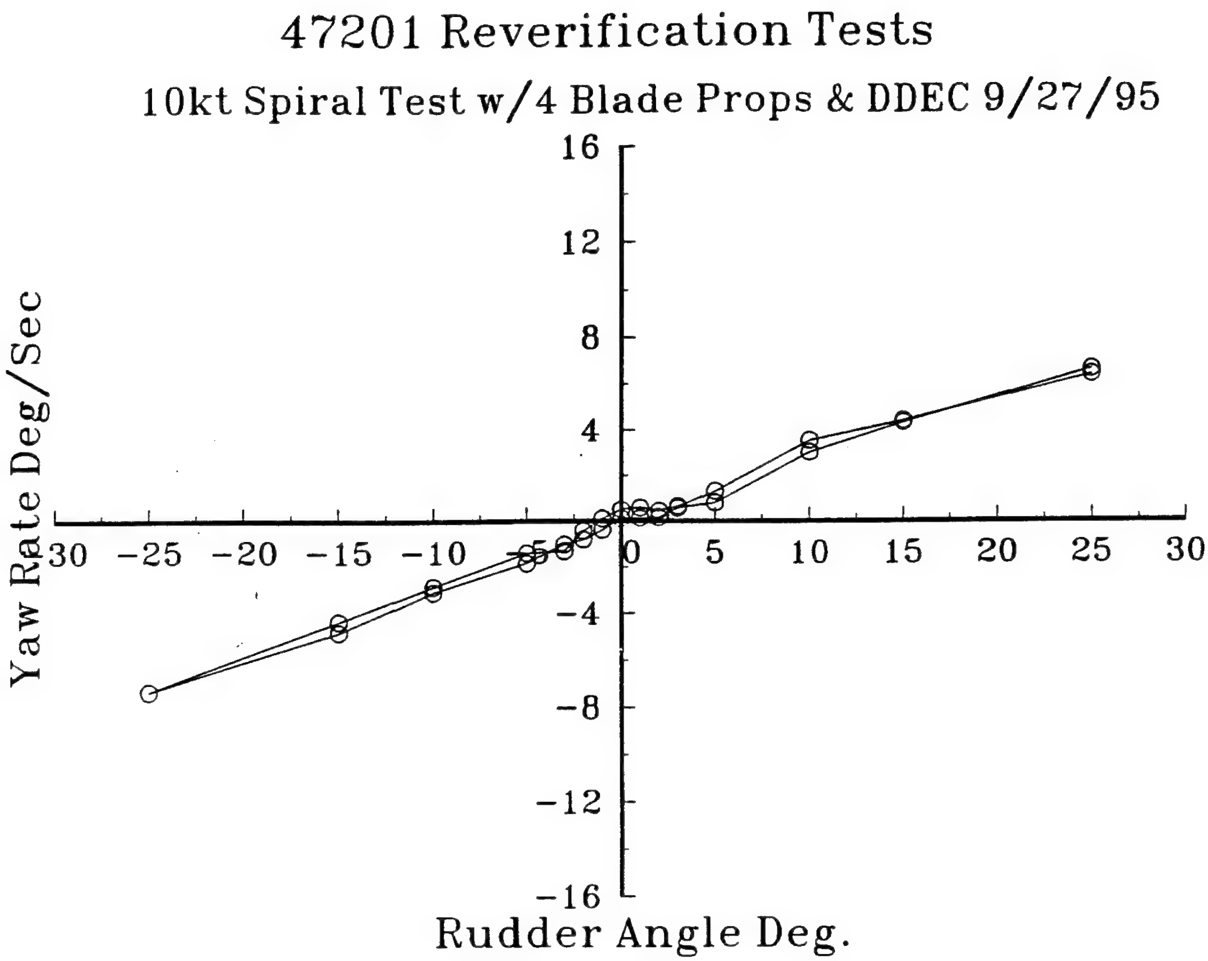


Figure 14. 10 KT Spiral Test

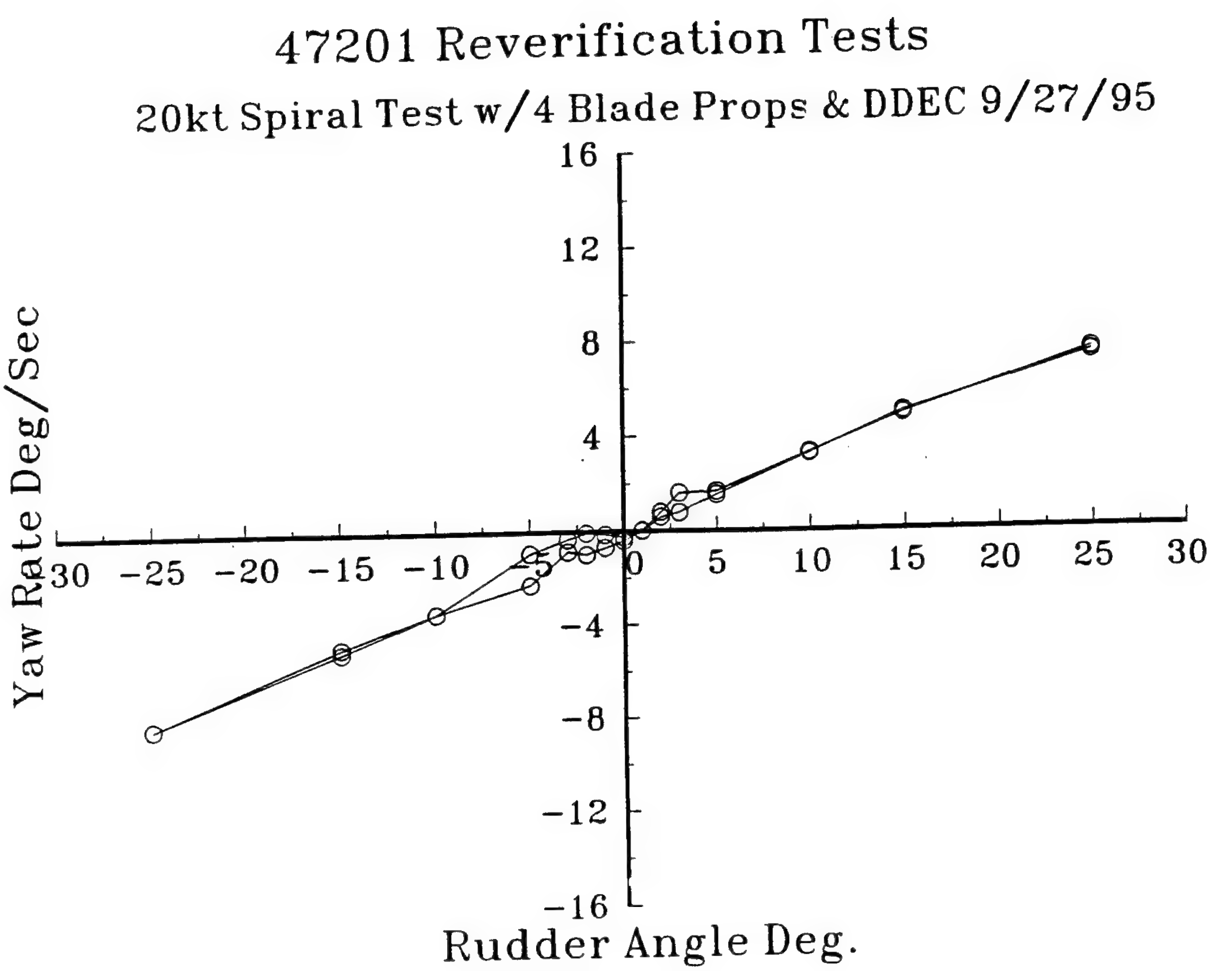


Figure 15. 20 KT Spiral Test

3.6 Pullout Maneuver

A pullout maneuver was conducted on the 47201 at speeds of 10 and 23 knots. Pullout maneuvers were conducted by performing normal turning circle tests with the rudder hard over. However, after turning 360 degrees the rudder was returned to amidships or neutral rudder angle. The yaw rate sensor from the motions package was remotely monitored by test personnel to determine when or if the yaw rate steadied to zero. The boat was considered to be directionally stable if the yaw rate readings exponentially decayed to zero. If the yaw rate did not approach zero or continued to turn with some residual rate then some degree of instability exists. The pullout tests were conducted to port and starboard.

The pullout maneuvers conducted to port and starboard at 23 knots indicated a directionally stable boat. In both directions the yaw rate went to zero quickly. This can be seen in Figure 16 and was noted by the test personnel monitoring the yaw rate sensor signal.

The pullout maneuver performed to starboard at 10 knots had a yaw rate that went to zero. However, the 10 knot maneuver to port had a yaw rate that did not completely go to zero. This is apparent in Figure 17 which demonstrates that the boat continues to turn without straightening out. The test to port was conducted again but with 2 degrees of starboard rudder checking to achieve a yaw rate of zero. This meets the acceptable loop width criteria for allowable instability which is generally applied to large ships. It is difficult to ascertain why this marginal instability exists in a port maneuver at 10 knots only. It is possible that a small degree of geometrical asymmetry in either the hull, propeller center alignment relative to the keel, or rudder alignment exists that has some dynamic influence over course keeping at slow speeds only.

3.7 Zig Zag Maneuver

The zig zag maneuver was conducted to quantify the ability of the rudder on the preproduction MLB to control the vessel. The data collected on the zig zag trial provides a measure of the ability of the MLB to rapidly change course and provides an operational view of the amount of anticipation required of a coxswain when operating in restricted waters or rescuing persons in the water (PIWs). Figure 18 illustrates the important performance measures in a zig zag maneuver.

The zig zag maneuvers were performed by the introduction of a 20 degree rudder from an initial straight course which was maintained until an equivalent degree of yaw, i.e., 20 degrees, took place. The opposite hand 20 degree rudder was applied and held until the equivalent degree of yaw was reached. The procedure was repeated several times.

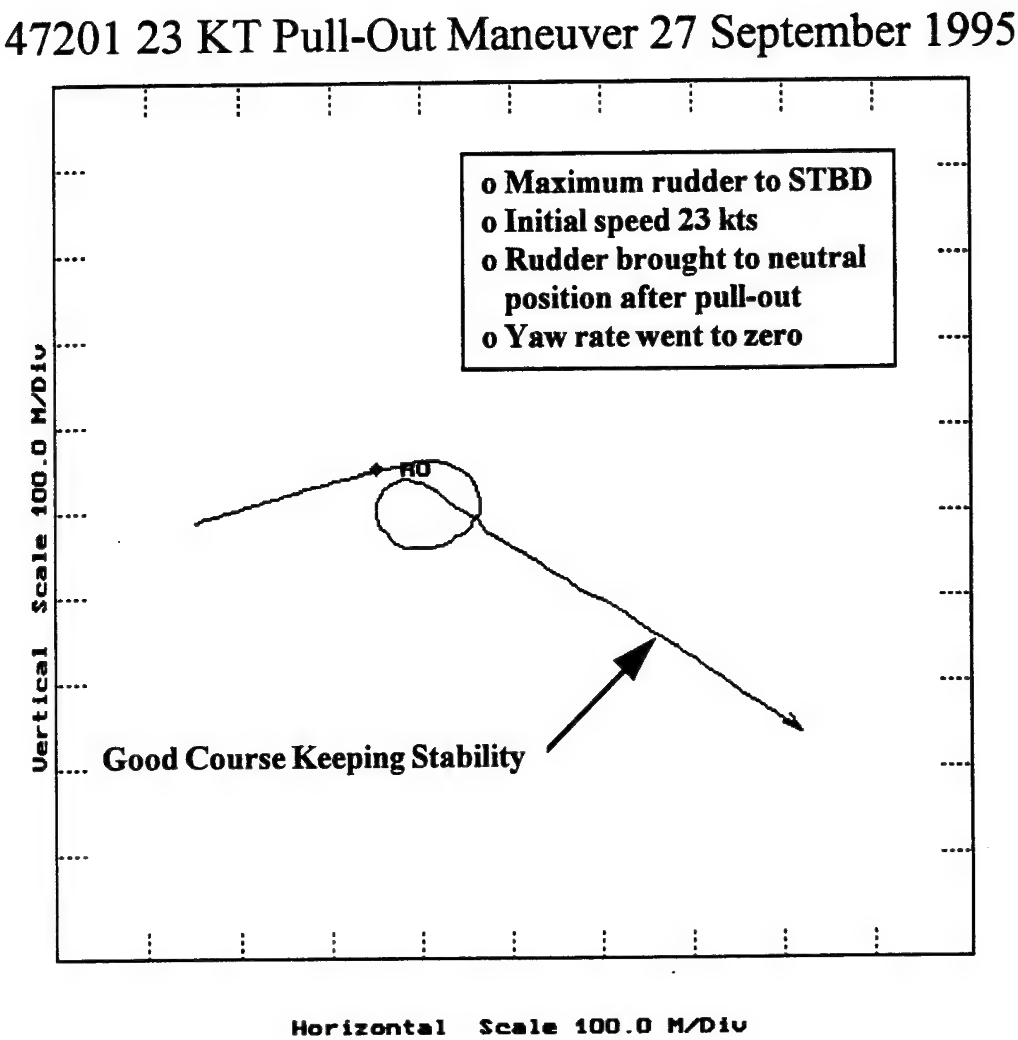


Figure 16. 23 KT Pullout Maneuver

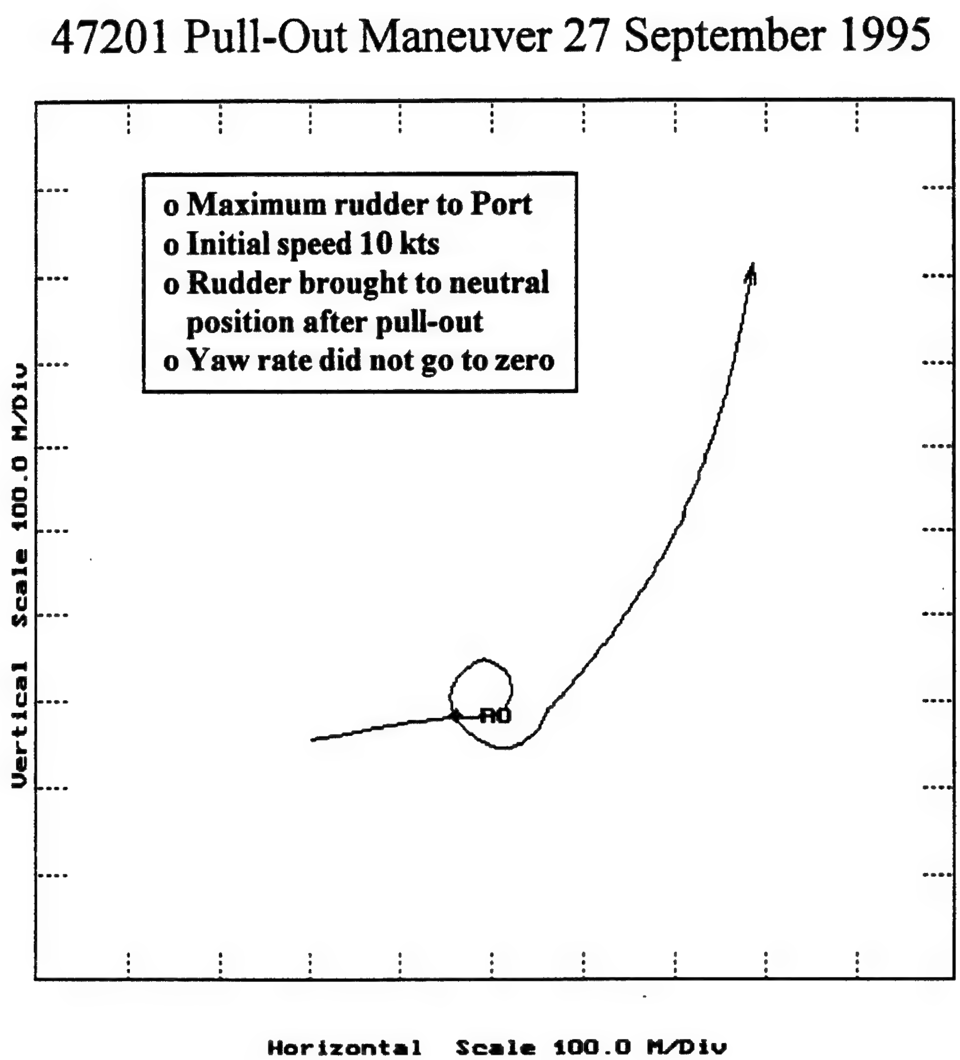


Figure 17. 10 KT Pullout Maneuver

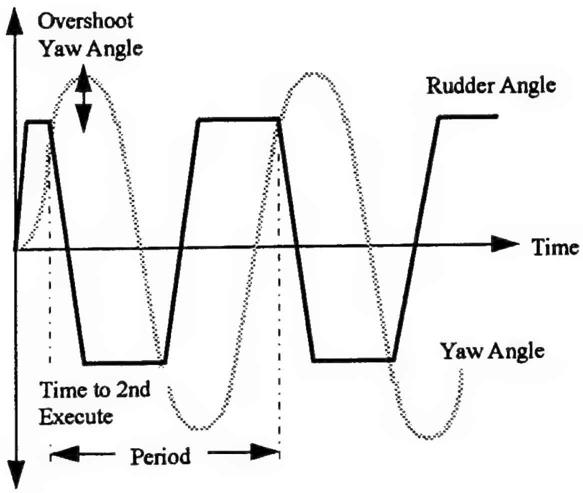


Figure 18 Zig Zag Maneuver Characteristics

Zig zag maneuvers conducted on the 47201 included 10 knot and 20 knot trials at 20 and 30 degree rudder. Zig zag maneuvers were conducted on the prototype in Reference (1) at 10 and 20 knots for 20 degree rudders only. Figures 19 and 20 demonstrate the results of 10 knot and 20 knot zig zags at 30 degree rudder. Figures 21 and 22 demonstrate the approximate overshoot width of path for maneuvers presented in Figures 19 and 20, respectively. The figures present one direction trials only. Reciprocal zig zag courses were run so that averages could be made. The averaged results for the 30 degree maneuvers are presented in Table 6.

Table 6 - 47201 30 Degree Zig Zag Maneuvers

47201 30 Degree Zig Zag Maneuvers (Averaged)				
Speed	Time to 2nd Execution	Average Period	1st Overshoot Angle	Average Overshoot Angle
10 kts	4.6 sec	28.4 sec	42.5 deg	12.3 deg
20 kts	4.8 sec	26.3 sec	47.6 deg	16.8 deg

Table 7 Preproduction and Prototype MLB 20 degree Zig Zag Trial Comparison

Speed	Time to 2nd Execution	Average Period	1st Overshoot Angle	Average Overshoot Angle
10 kts	7.1(4.4) sec	32.8(14.9) sec	22.2(4.5) deg	20.2(11.5) deg
23 kts	3.4 sec	23.7 sec	20.5 deg	13.2 deg
25 kts	(3) sec	(7) sec	(4.5) deg	(8) deg

'( )' represent 47200 results

The time to reach the second executable in a zig zag maneuver is a direct measure of the MLB's ability to rapidly change course, i.e., this time would generally improve with better

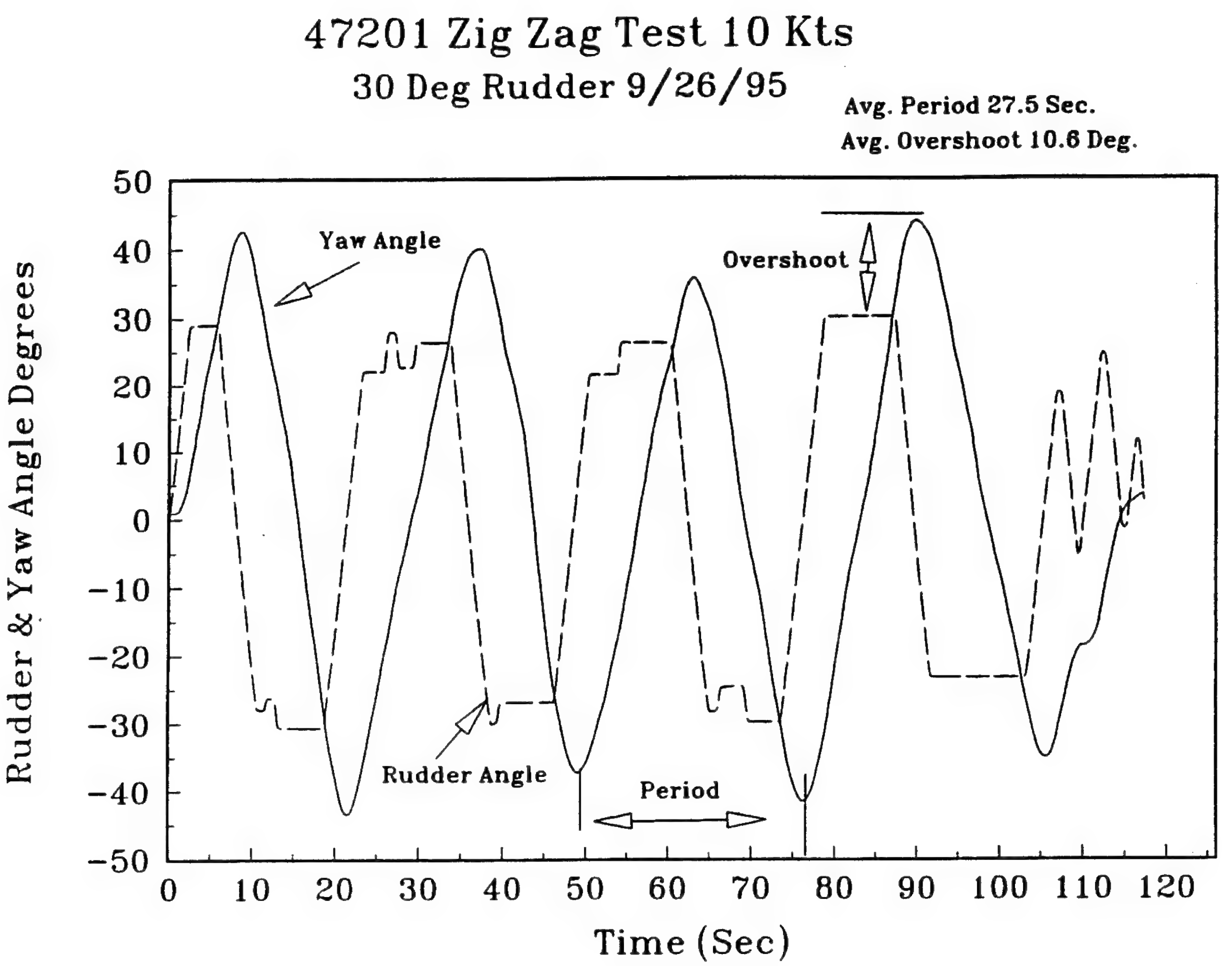


Figure 19. 10 KT Zig Zag Maneuver

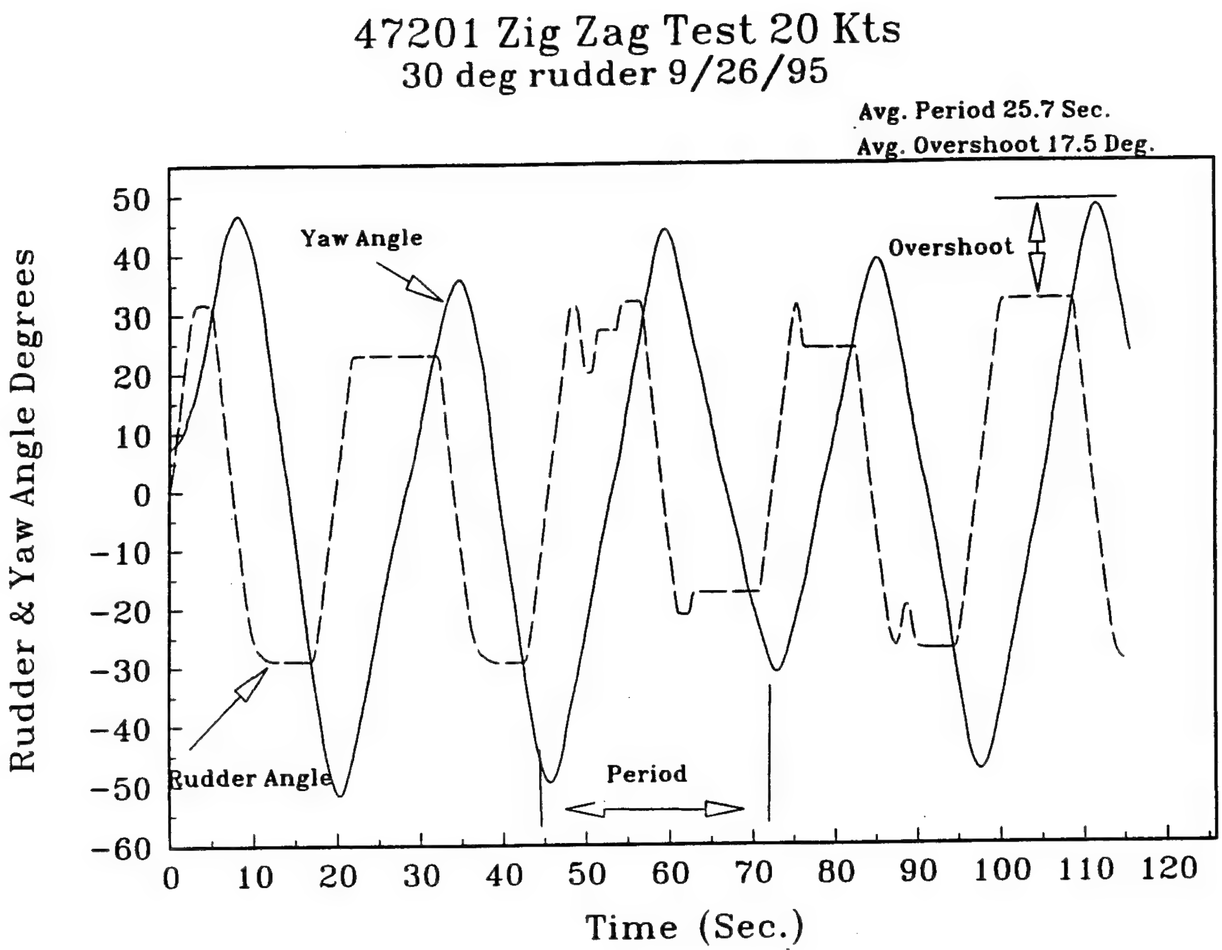


Figure 20. 20 KT Zig Zag Maneuver

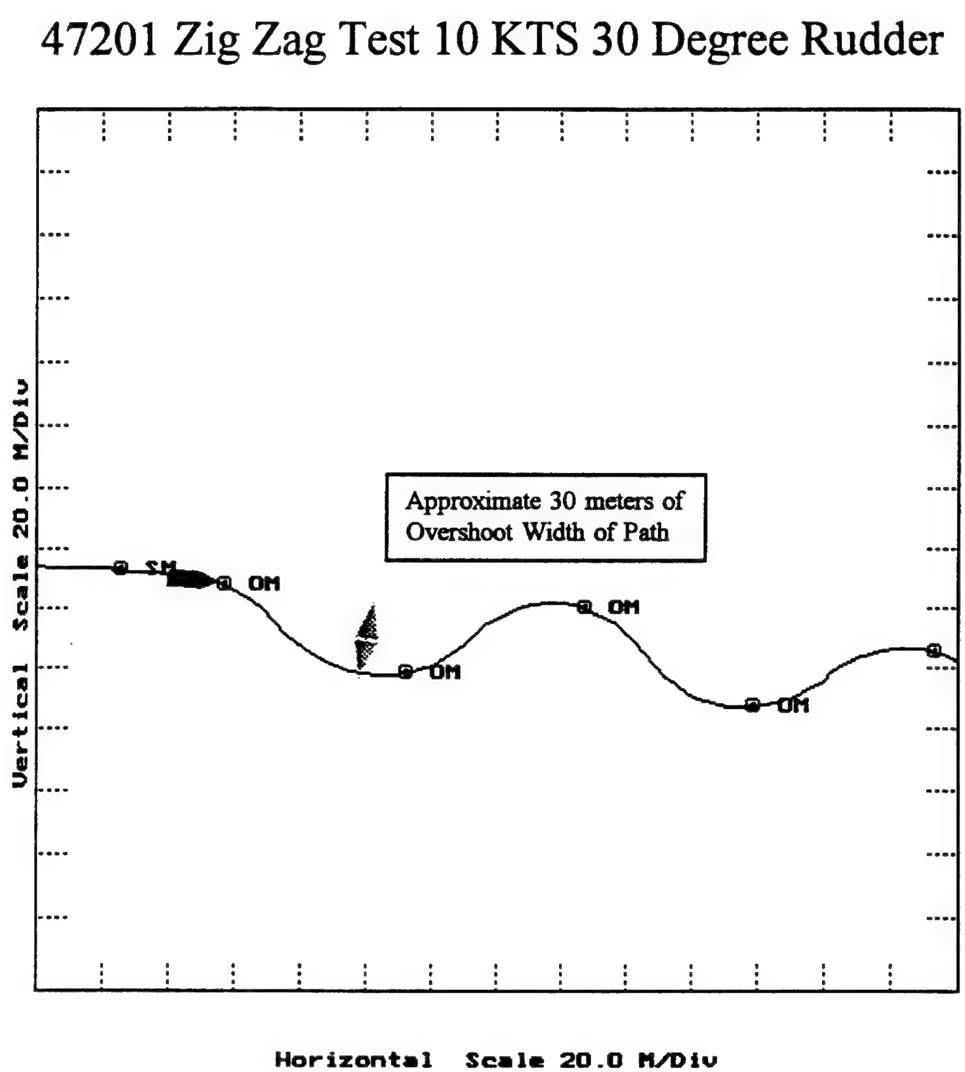


Figure 21. Zig Zag 10 KT 30 Degree Overshoot Path Width

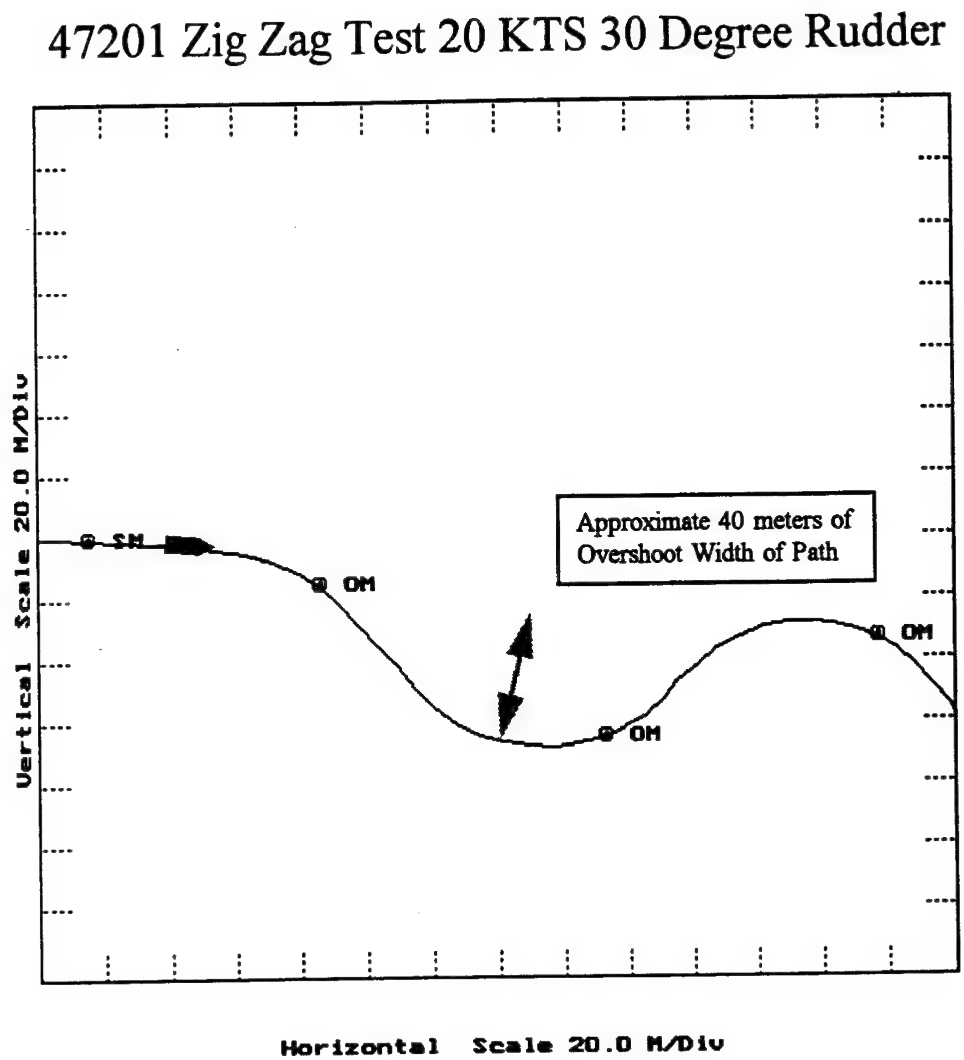


Figure 22. Zig Zag 20 KT 30 Degree Overshoot Path Width

rudder effectiveness but would get worse with controls-fixed stability. It is apparent from Table 7 that the preproduction MLB has less ability to rapidly change course than the prototype.

The overshoot angle and overshoot width of path are measures of the amount of anticipation required of the coxswain in restricted waters. The 47201 was shown to turn slightly better than the 47200 and since overshoot is a function of turn rate, the vessel with the better turn rate will have the bigger overshoot angles. However, the overshoot angles of the 47201 are significantly larger than those of the 47200. This will require the 47201 MLB's coxswain to react faster and anticipate more when maneuvering the boat.

The change in performance may be related to the increased weight and strut extensions. Zig zag comparisons were made in Reference (4) between the 1.9 ft^2 rudders without strut extensions and 2.1 ft^2 rudders with strut extensions at 25 knots. It was determined that, even though the larger rudders should have provided better control, the combination of the larger rudders with strut extensions had less maneuverability than the smaller rudders without strut extensions.

The overshoot path widths captured with the Tacman4 system are shown in Figures 21 and 22. The '@ SM' and '@ OM' represent the start of the maneuver run, and point when the rudder was placed hard over to 30 degrees.

3.8 Speed - Trim and Dynamic Instability Discussion

Dynamic instabilities can manifest themselves in many ways including chine riding, porpoising, bow steering, etc. Dynamic instabilities are speed related and can occur when dynamic forces dominate over buoyant forces as in planing craft. The prototype MLB exhibited some behavior indicative of dynamic instabilities during the DT&E testing. For example, the 47200 had annoying tendencies to heel 3 to 6 degrees to port while running at speeds greater than 20 knots. This phenomenon was not apparent on the 47201 preproduction MLB. The prototype also had broaching and large roll moment problems associated with hard rudder maneuvers at high speed. Eventually, these effects were minimized on the 47200 by selecting smaller vertical rudders with no skeg appendages over the large canted rudders. Excessive heel (of the magnitudes recorded on early hull configurations of the prototype) in a high speed turn was not observed or recorded in the reverification trials. The maximum heel in a 24 knot turn on the 47201 with the rudder hard over was approximately 12 degrees.

Measurements of trim versus speed were made in conjunction with the power versus speed measurement (see Figure 24) on 27 September. The trim measurements were made by the gyro-stabilized pitch sensor in the motions package installed near the center of gravity of the MLB. The speed data was captured using the Tacman4 GPS system which corrected for set and drift encountered in the test area. The speed data in this case was not as reliable as the reciprocal speed-power runs to be discussed in Section 3.9 because only

one dead-in-the-water (DIW) Tacman4 run was measured and used for set and drift corrections. Speed and trim data were collected at 50 RPM increments up to full speed.

The trim measurements collected were compared to prototype test speed versus trim results in Reference (1). The results are comparable to the speed-trim characteristics of the 47200 with similar weight and LCG configuration. However, more detail was collected in the reverification testing. Generally, the 47-FT MLB preproduction has retained the good trim performance features of the prototype. The 47201 speed versus trim data is plotted in Figure 23.

There appears to be some scatter in the data of Figure 23 which was curve fitted using a second order polynomial. Although there is considerable scatter in the data collected, a noticeable drop in speed was physically observed around 1850 RPM at approximately 17.5 knots. Additional data points should have been taken around that speed to resolve the shape of the curve to determine if a trim instability existed. The data results are inconclusive in this regard.

The preproduction DDEC MLB in its present configuration will not exceed its design speed of 25 knots in normal operational condition. The one advantage of a slightly slower MLB is the reduced likelihood of encountering dynamic instabilities in service. However, if future changes are made to the configuration of the production run MLBs. that significantly increase its speed, weight, or move the LCG forward, then the potential for dynamic instabilities may increase. If this takes place, it will be very important to recognize and investigate any instabilities noted by the MLB coxswains and operators.

3.9 Speed-Power Evaluation

Speed-power measurements were conducted in DDEC testing in November 1994 in Reference (2). Figure 24 compares the reverification speed power data to the data collected in November of 1995. The characteristic hump speed region is apparent in all three weight conditions. The reverification speed-power data were collected on 26 September. Reciprocal courses were run at selected speeds. Horsepower and TACMAN4 GPS speed were averaged. Although, the reverification results follow the 42,320 lbs. trial weight more closely than the 40,218 lbs. results, the data in Figure 24 are in general agreement. The speed versus RPM data are also in general agreement with Reference (2) results.

Figure 25 presents a plot of percent engine load as a function of RPM for the speed-power data. The percent DDEC engine load increases sharply to 70% around 1400 RPM (approximately 12 knots) which is indicative of the additional work the engine must utilize to get the boat on plane. It was observed that outside noise levels increased to uncomfortable levels in this RPM range. These noise levels are discussed in Section 3.10.

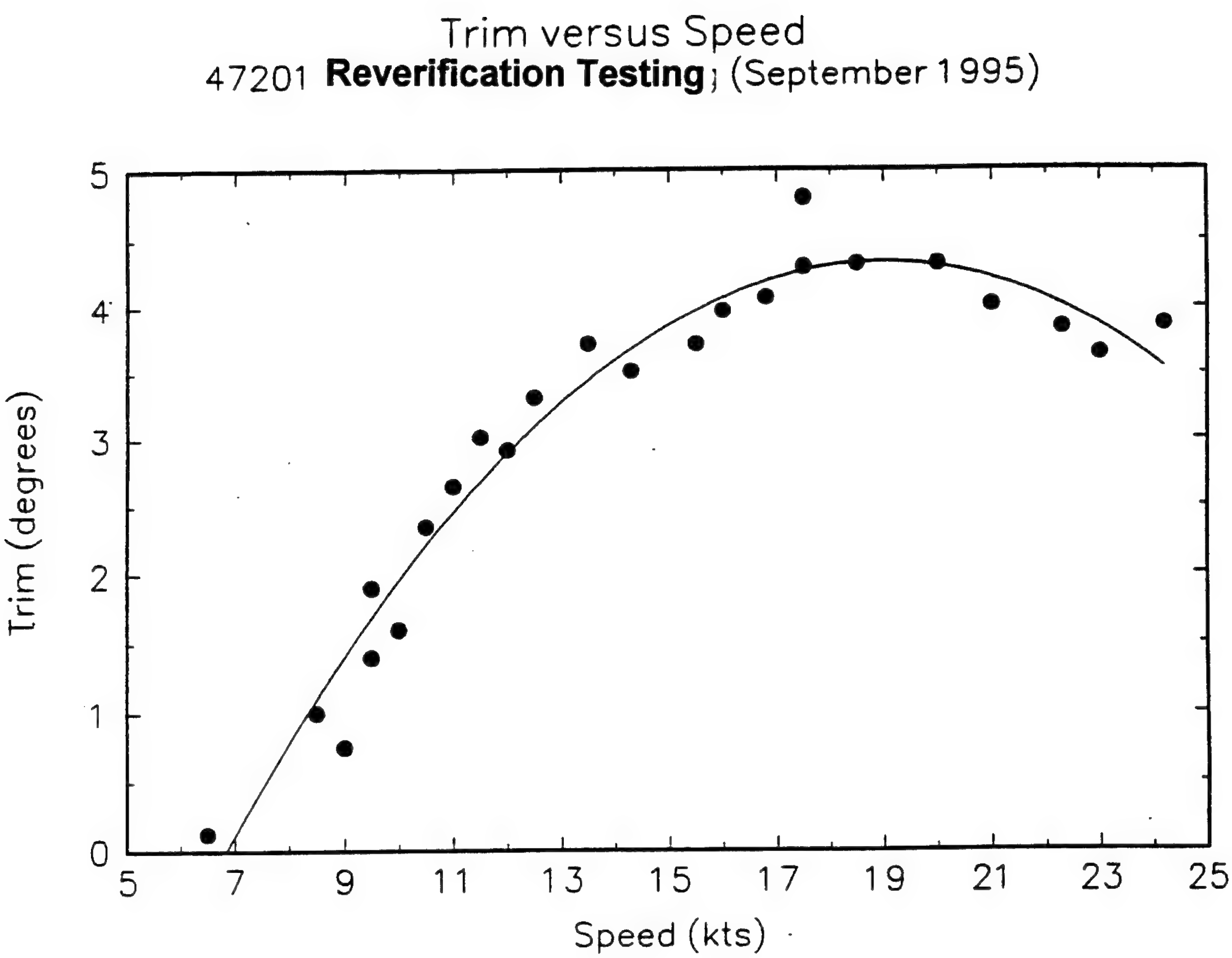


Figure 23. Trim versus Speed

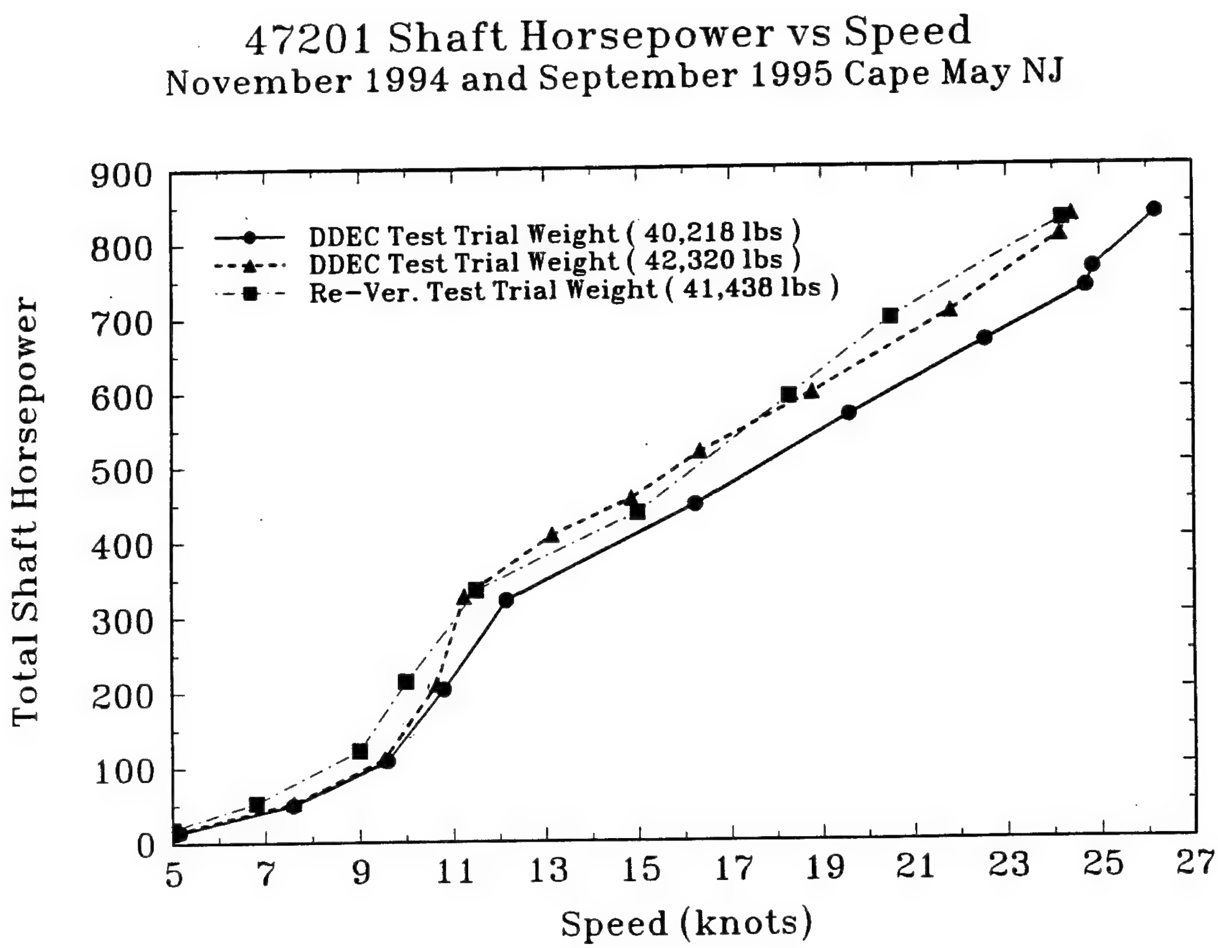


Figure 24. Speed-Power Trial

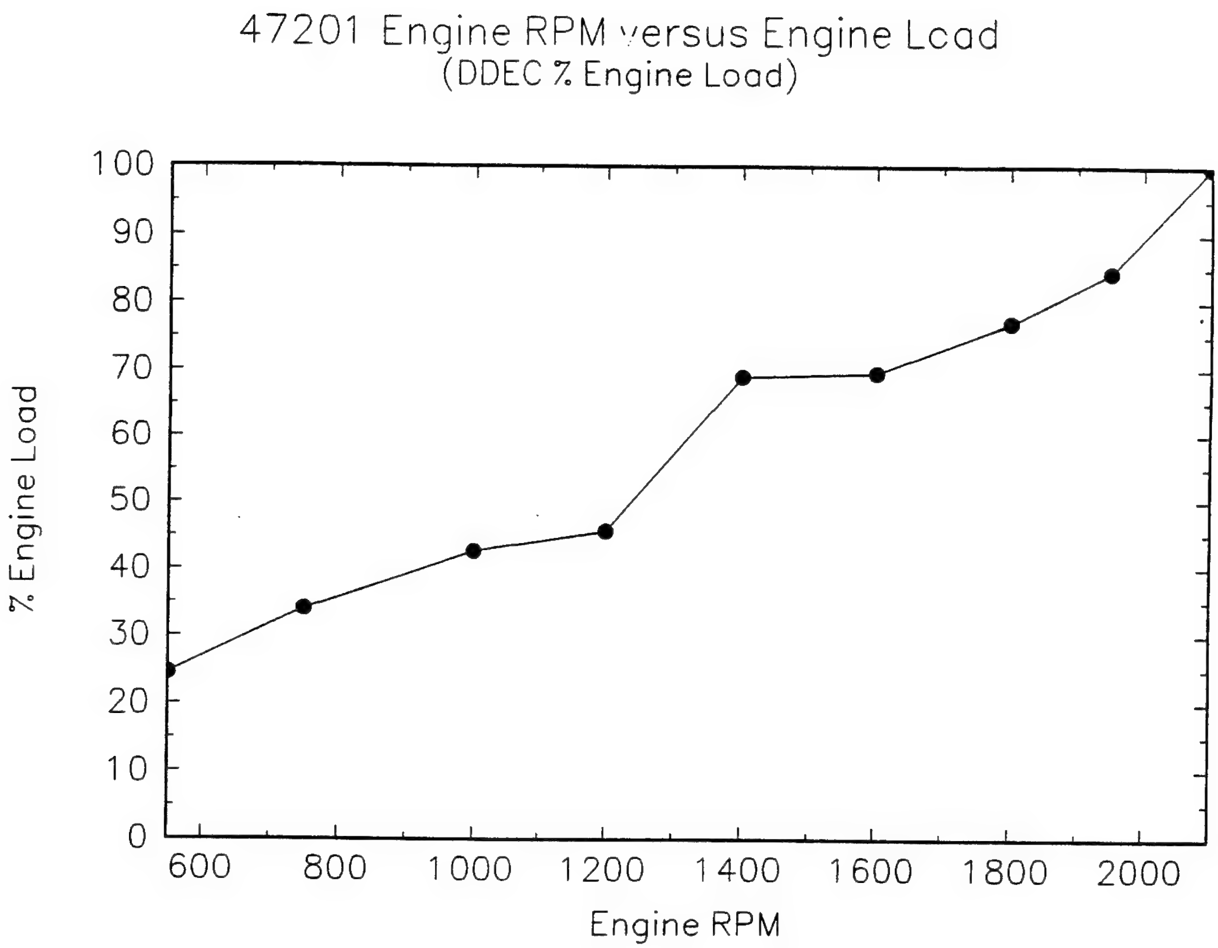


Figure 25. RPM vs. Engine Load

In the original DT&E tests of Reference (1) the prototype was reported to have a top speed of 27.1 knots in its normal outfit condition. The top speed recorded in the DDEC tests of Reference (2) was 26.2 knots. The top speed recorded in the preproduction MLB maneuvering reverification testing is 24.2 knots. The following summarizes the top speeds recorded on the prototype and preproduction MLBs.:

- 1991 Prototype DT&E Testing - 27.1 knots @ 40,410 lbs.
- 1994 Preproduction DDEC Testing - 26.2 knots @ 40,320 lbs.
- 1995 Preproduction Maneuvering Reverification Testing - 24.2 knots @ 41,438 lbs.

Station Cape May installed new 4-bladed propellers and eliminated a minor problem with the throttles not tracking properly. The station claims that the MLB can get an additional 40-50 RPM for a maximum of 2180 RPM after the reverification tests. The top RPM achieved during the reverification test was 2140 RPM whereas the prototype achieved its top speed of 27 knots at 2300 RPM. The station reported new average top speeds of 25.5 knots. This speed reflects a preproduction MLB in top condition in terms of a clean hull, new propellers, and accurate throttles. Maintaining this condition in service to retain a top speed of 25 knots may be unrealistic. Therefore, since 41,367 lbs. was determined to be normal outfitted weight, it is anticipated that the 47201 can no longer be expected to achieve top running speeds of 25 knots or more in service.

3.10 Noise Evaluation

Limited sound data were collected on the 47201 at several key locations during these trials. The locations tested were:

- tow bitt - measured just forward of the tow bitt facing aft
- engine room - measured between engines approximately 3 feet above the deck
- enclosed bridge - measured between the coxswain's chairs (helmsman's ear)
- survivor's space - measured centrally in the space with doors closed

A Bruel & Kjaer (B&K) 2231 precision sound meter was used in the fast response mode to record both "C" and "A" weighted measurements. Sound pressure level "A" weighted noise results from 26 September measurements are tabulated in Table 8.

Table 8 Comparison of "A" Weighted Noise Levels

47201 A Weighted Noise Levels (dB re 20 μPa)				
RPM	Tow Bitt	Engine Room	Enclosed Bridge	Survivor's Space
550	77	101	70	75
750	80/(82)	103/(104)	73/(77)	76
1000	84/(84)	106/(107)	74/(78)	77
1200	85/(87)	108/(109)	75/(85)	80
1400	89/(89)	110/(109)	85/(85)	83
1600	87/(92)	111/(110)	79/(81)	85
1800	89	115	84	86
1950	93/(92)	114/(115)	84/(88)	87
2100	93/(93)	115/(115)	84/(86)	89

Note: ( ) is 47200 noise data collected in January 1991;
Enclosed bridge data were collected with
Survivor's Compartment door open

An approximate comparison can be made with "A" weighted noise data collected on the 47200 at different speeds in January of 1991. This is done in Table 8. The results for the engine room and tow bitt are comparable at these speeds. The results for the enclosed bridge or helmsman's ear are higher for the 47200 because the Survivor's Compartment door was open.

A general goal specified in OPNAVINST 9640.1 is that the "A" weighted sound level at full throttle should not exceed 84 dB at the helmsman's station.

Additional "A" and "C" weighted noise data were taken on 27 September in the Survivor's Compartment and near the tow bitt. These measurements were conducted at 50 RPM increments. The noise data from the tow bitt are plotted in Figure 26. This plot was made because of audible higher noise conditions noted from the flying bridge and on the deck in an RPM range of 1350 to 1500 RPM. The noise levels appear high in this range. This RPM range is representative of the high end of towing RPMs and the speed at which the 47-FT MLB begins to plane. The high noise levels around 1450 RPM of 94 dBA may be of concern if crew members must work outside during a long case such as a towing mission. Commercial (OSHA) standards cite 90 dBA as the limit for an eight hour work schedule without requiring ear protection.

The excessive noise near the tow bitt and in the engine room, commented on by the crew as well, in this RPM range may be due to the new mufflers in combination with the increased engine load (see Figure 25). The new exhaust mufflers did not have any insulation or acoustical lagging on at the time of these tests. It is not possible to determine the noise source without further testing. It is recommended that additional noise measurements be conducted on the 47201 after modification and lagging work are

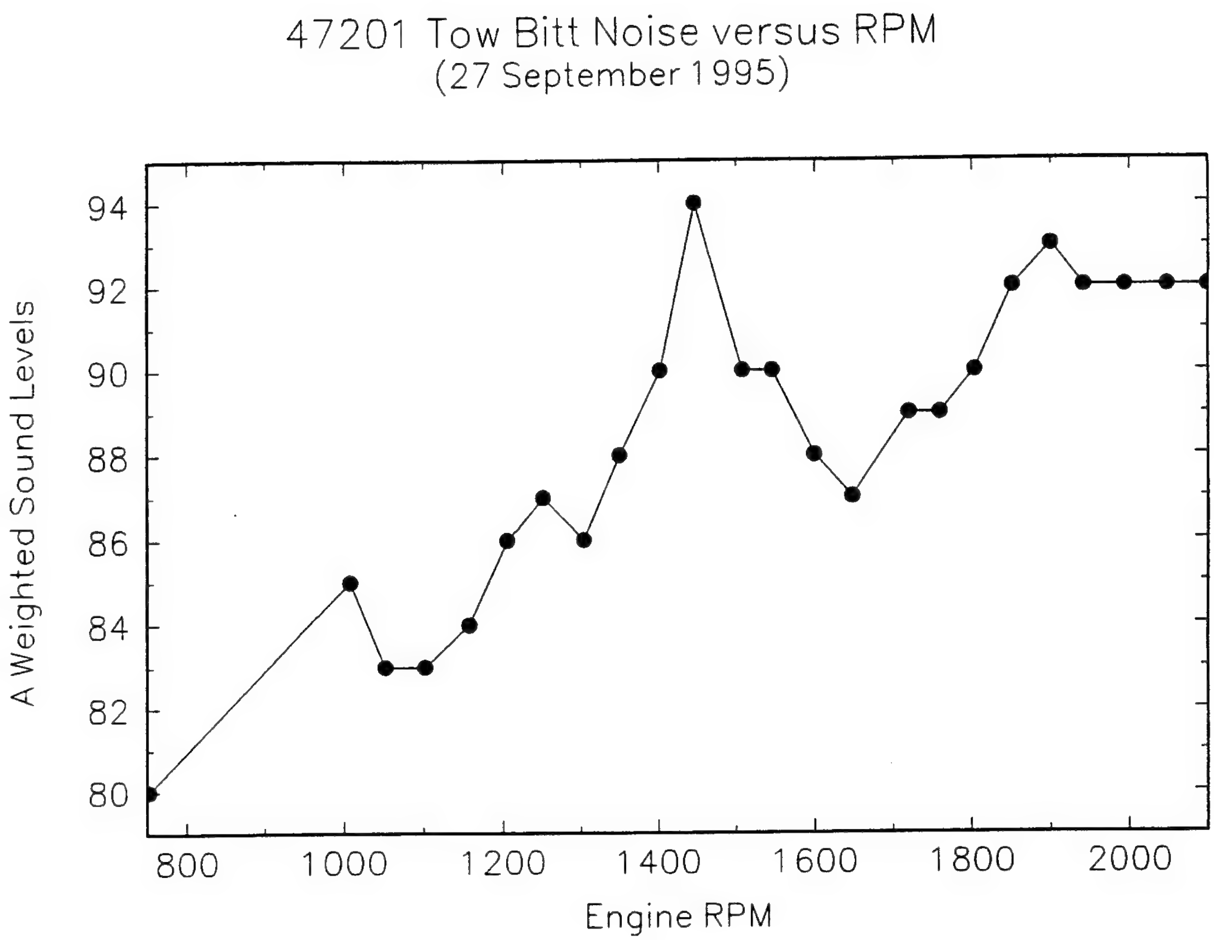


Figure 26. 47201 Tow Bitt Noise versus RPM

complete. In addition to standard "A" weighted noise measurements, 1/3 octave band measurements are also needed to resolve the frequency content of the noise source.

The muffler exhaust was raised approximately 1.5 feet above the original position near the waterline. The new location of the exhaust ports increases the potential for some backdrafts of diesel fumes at slow speeds, e.g., towing cases. The combination of increased noise and exhaust fumes can have a detrimental effect on crew performance and should be investigated further.

4 Summary/Conclusions

Reverification maneuvering and control testing was performed on a preproduction 47-FT MLB to quantify any significant differences since the 47-FT prototype verification testing. The testing conducted on the 47201 represents a few days of trials and does not duplicate the comprehensive T&E conducted on the prototype in Reference (1). It does, however, provide an updated view of the present MLB performance after growth pains associated with replacement engines and other implemented engineering change proposals to make the 47-FT MLB a better rescue boat.

The 47201 preproduction MLB has experienced a weight growth of 1,134 lbs. in its normal outfit weight configuration since the prototype MLB was evaluated. Turning performance, speed-trim characteristics, and directional stability demonstrated in the trials are comparable to the prototype performance. The 47201 zig zag maneuvers demonstrated reduced ability to rapidly change course and an increase in anticipation required of the coxswain operating in restricted waters compared to the 47200. Engine stalls during split throttle and crash back maneuvers represent a dangerous condition if applied in the wrong situation. The top speed of the 47201 is 24 knots as measured in the reverification tests compared to the top speed of 27.1 knots for the 47200. Noise levels are comparable except in speed ranges where the MLB begins to plane.

Further investigation is recommended into the interactions of the strut extensions and rudder if controllability improvements are desired for the production MLBs. The Coast Guard needs to develop and adopt new ship testing procedures to better evaluate its future high speed planing boats. The procedures used in Reference (3) are good baseline tests that should be applied to all sizes of vessels, but other procedures could be developed to better quantify dynamic characteristics of planing vessels.

5 References

1. D.E. Milburn, "Technical Characteristics Verification of the Prototype 47 FT MLB," Coast Guard Final Report, dated October 1991, Report No. CG-D-02-92.

2. R.M. Latas, "Technical Evaluation of the CG-47201 6V-92 Detroit Diesel Electronic Control (DDEC) Propulsion Modification, "USCG R&D Report No. CG-D-14-95.

3. "Principles of Naval Architecture - Vol. III," Society of Naval Architects and Marine Engineers, 1989.

4. Enclosure (1) "Results of Maneuvering Trials of the 47-Foot MLB with 2.1 Square Foot Vertical Rudders and Strut Extensions," Letter Report from USCG R&D Center to Commandant (G-AMB) 26 August 1992.

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Appendix A
Example Plots of Turning Heel and Yaw Data

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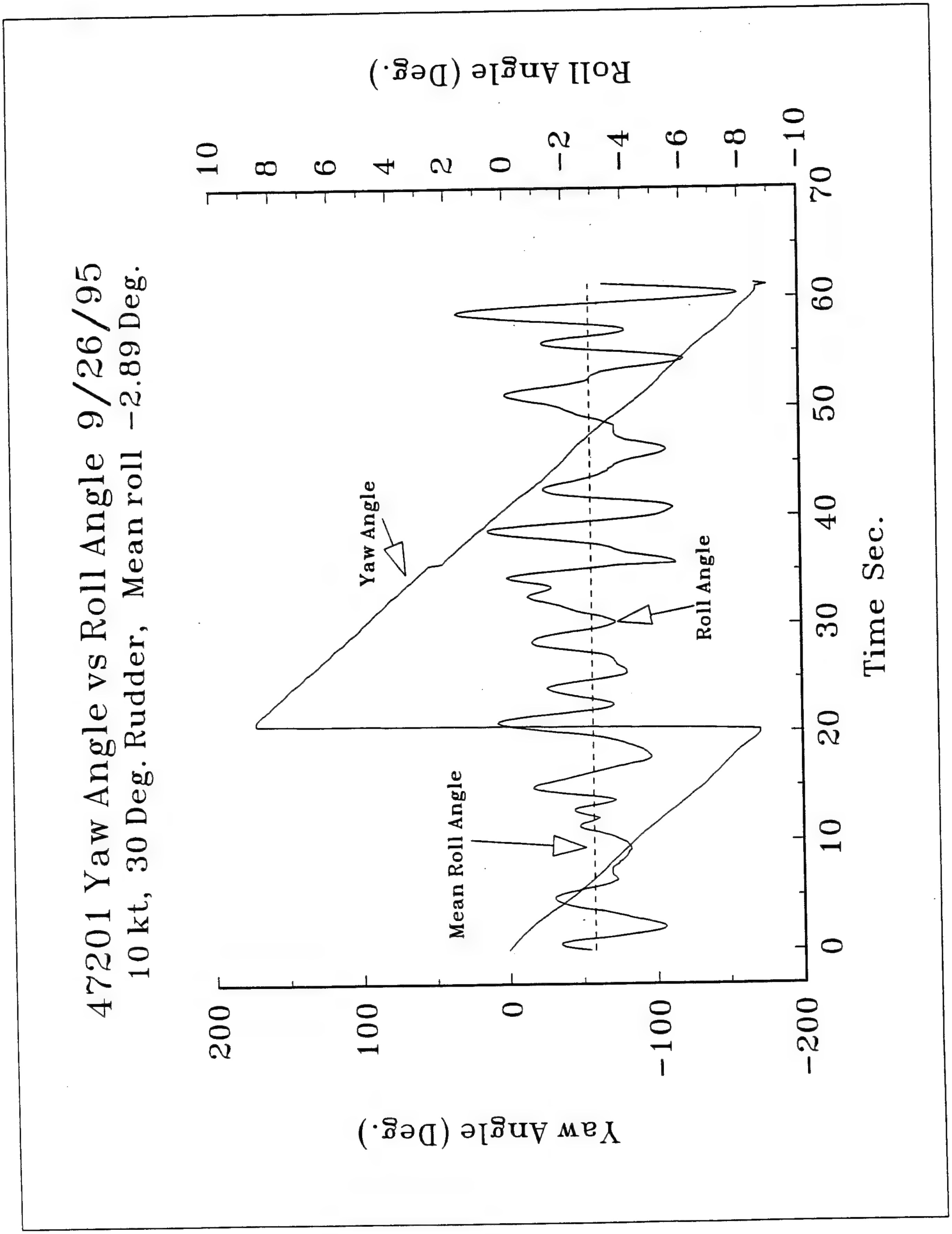
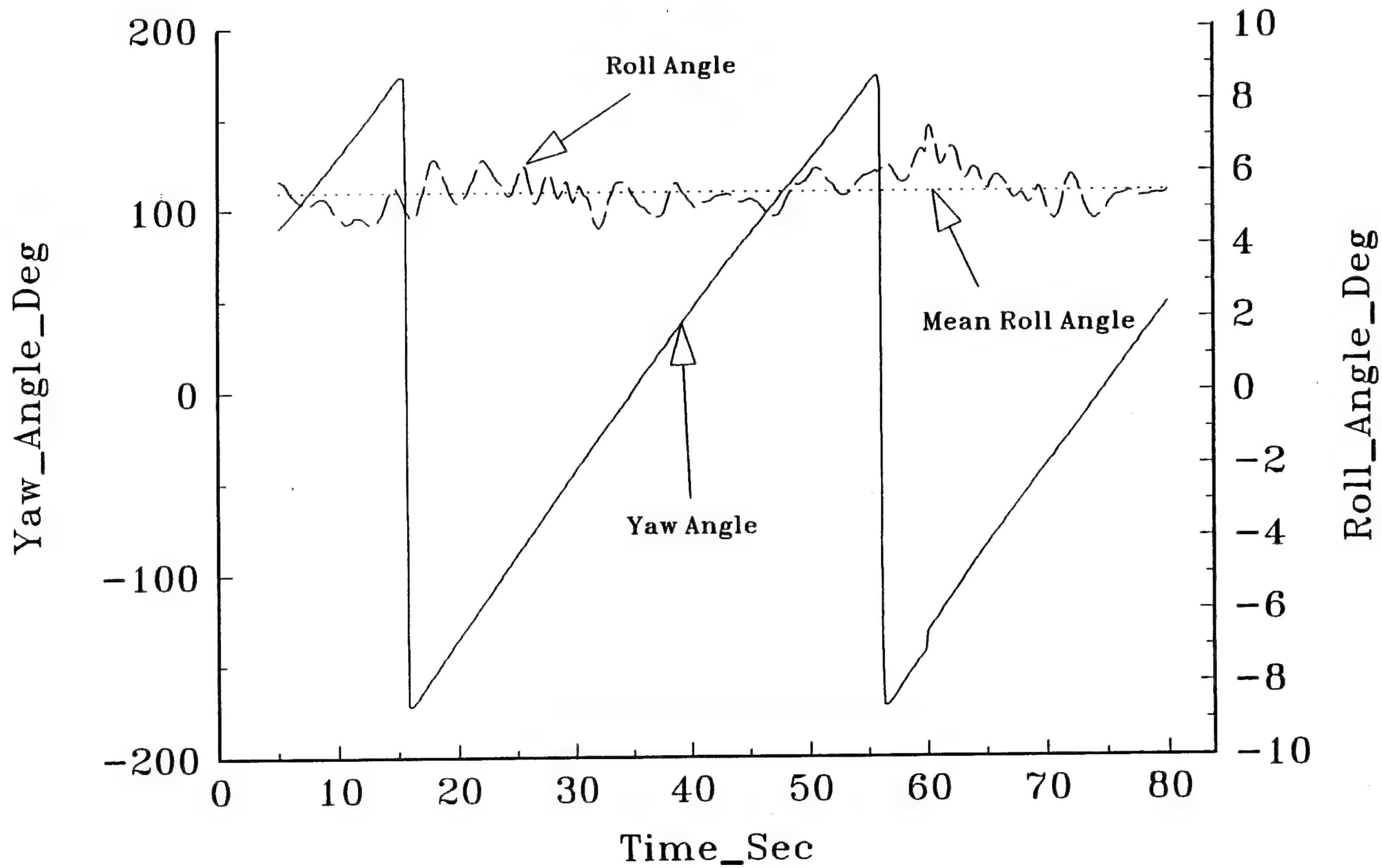
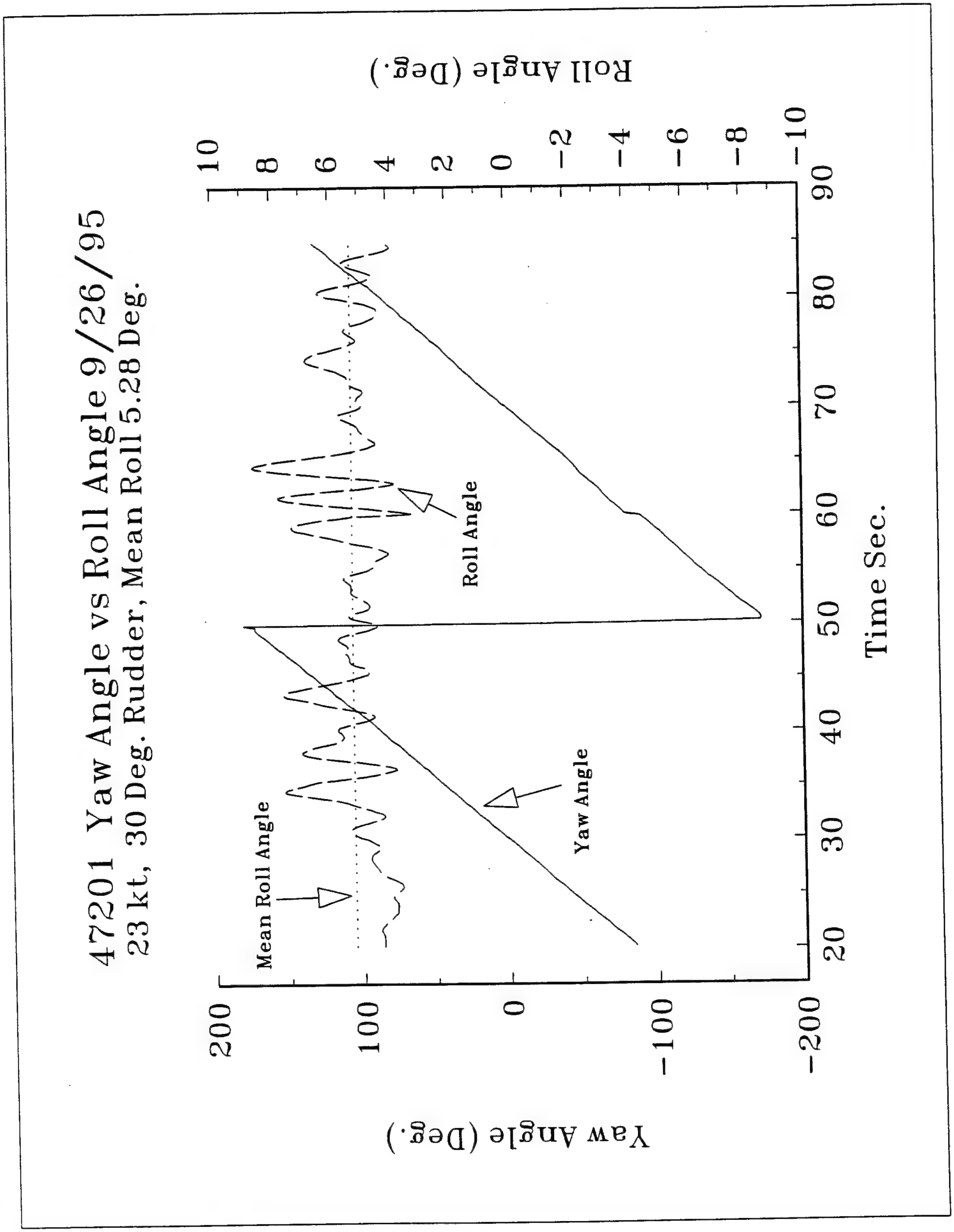


47201 Yaw Angle vs Roll Angle 9/26/95
10 kt, 30 Deg. Rudder, Mean roll −2.89 Deg.
Yaw Angle
Roll Angle
Mean Roll Angle
Yaw Angle (Deg.)
Roll Angle (Deg.)
Time Sec.
200
100
0
−100
−200
10
8
6
4
2
0
−2
−4
−6
−8
−10
0
10
20
30
40
50
60
70

47201 Yaw Angle vs Roll Angle 9/26/95
20 kt, 30 Deg. Rudder, Mean Roll Angle 5.47 Deg.




47201 Yaw Angle vs Roll Angle 9/26/95
23 kt, 30 Deg. Rudder, Mean Roll 5.28 Deg.
Mean Roll Angle
Yaw Angle
Roll Angle
Time Sec.
Yaw Angle (Deg.)
Roll Angle (Deg.)
200
100
0
−100
−200
10
8
6
4
2
0
−2
−4
−6
−8
−10
20
30
40
50
60
70
80
90

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Appendix B
Split Throttle Engine RPM vs Horsepower

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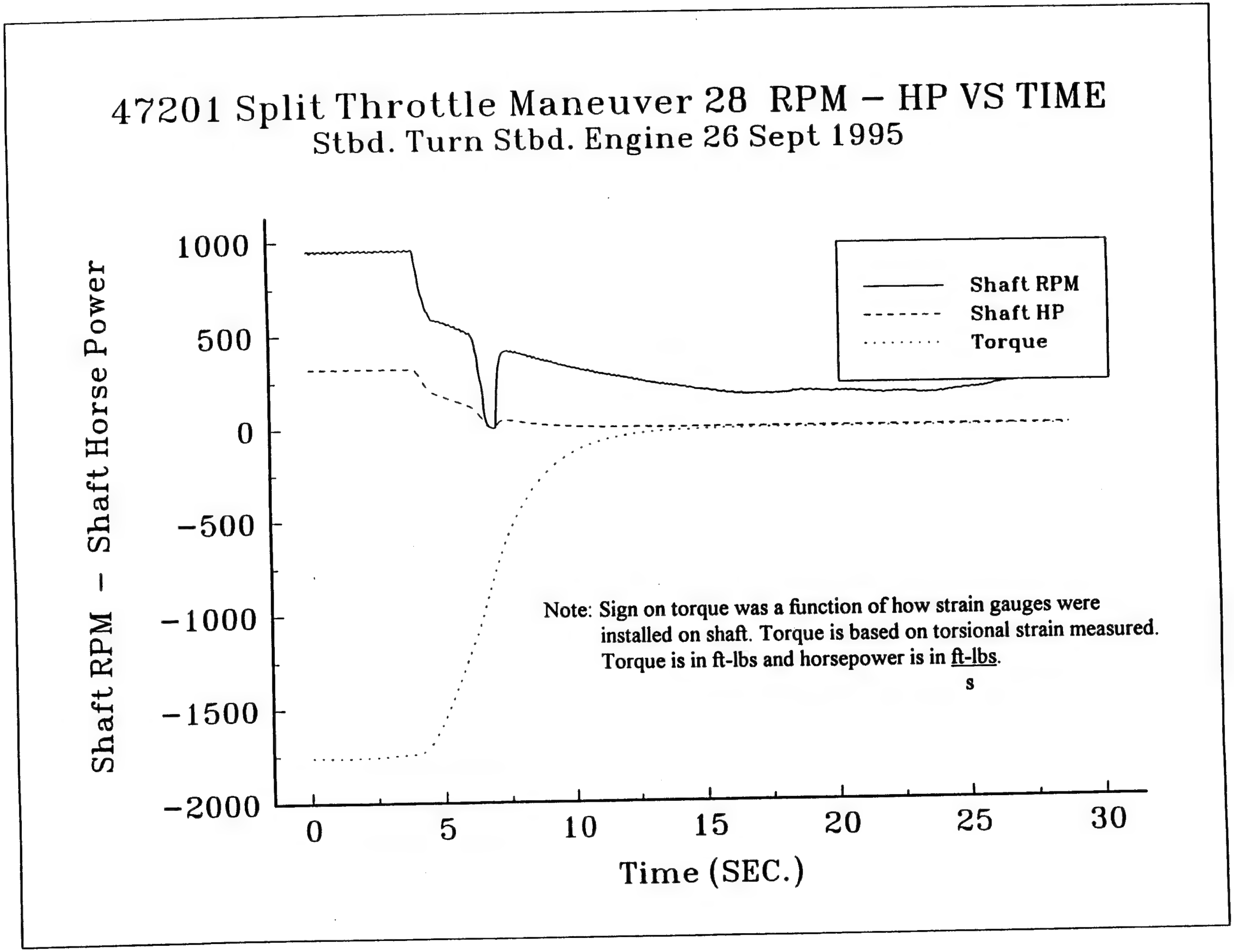
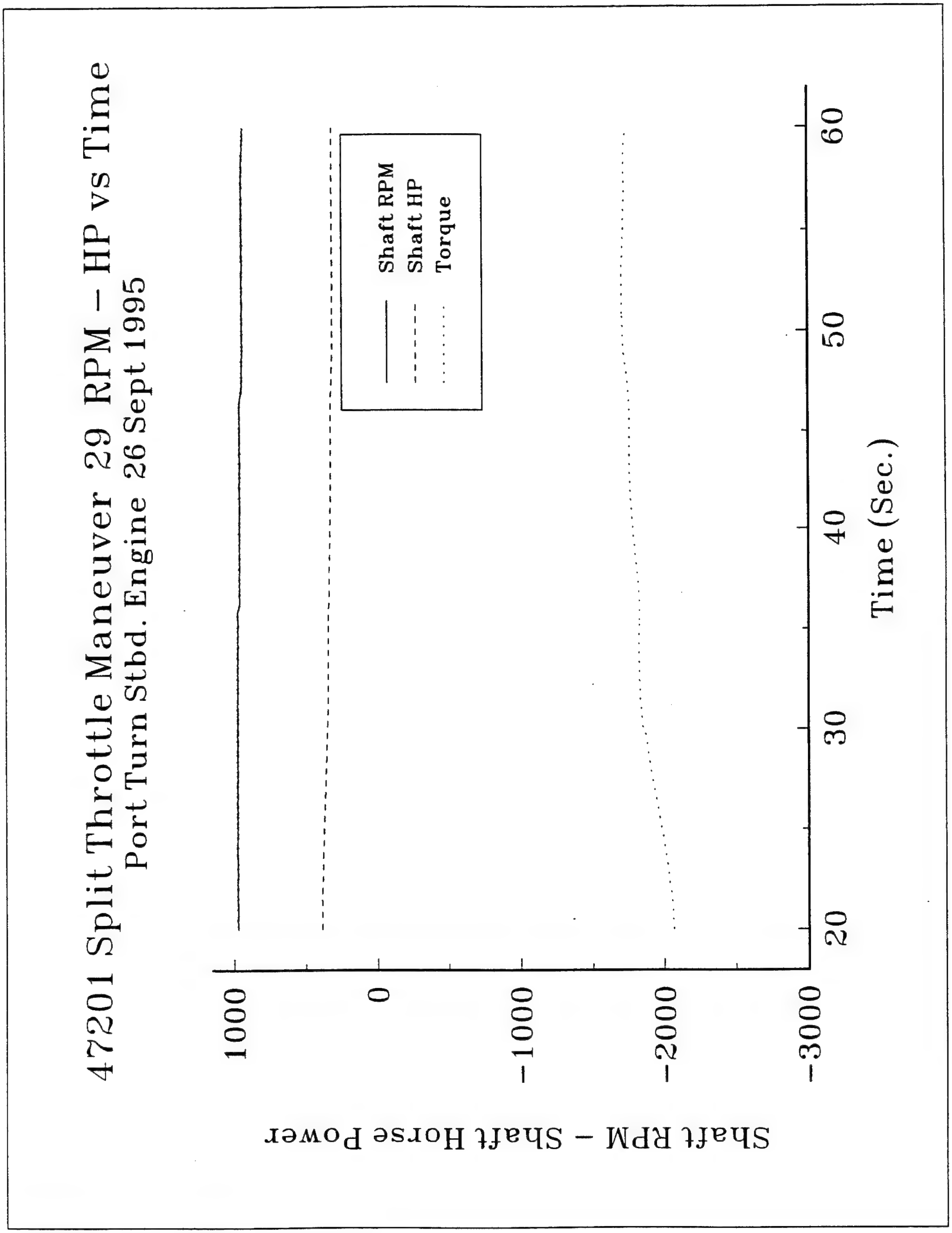

47201 Split Throttle Maneuver 28 RPM – HP VS TIME
Stbd. Turn Stbd. Engine 26 Sept 1995
Shaft RPM – Shaft Horse Power
1000
500
0
−500
−1000
−1500
−2000
0
5
10
15
20
25
30
Time (SEC.)
Shaft RPM
Shaft HP
Torque
Note: Sign on torque was a function of how strain gauges were installed on shaft. Torque is based on torsional strain measured. Torque is in ft-lbs and horsepower is in ft-lbs/s.


47201 Split Throttle Maneuver 29 RPM – HP vs Time
Port Turn Stbd. Engine 26 Sept 1995
Shaft RPM – Shaft Horse Power
1000
0
–1000
–2000
–3000
20
30
40
50
60
Time (Sec.)
Shaft RPM
Shaft HP
Torque

Appendix C
TACMAN Acceleration and Deceleration Data

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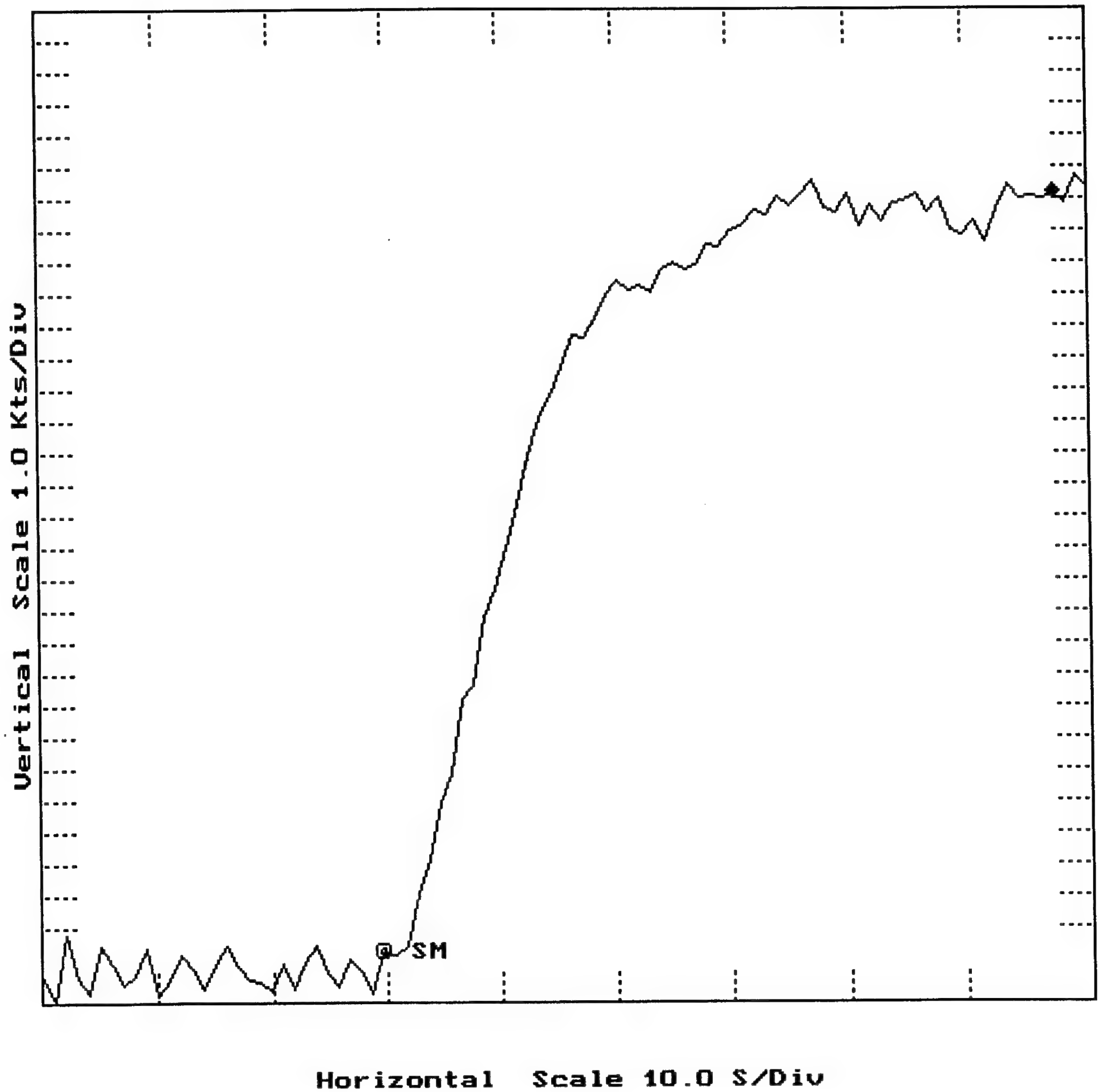
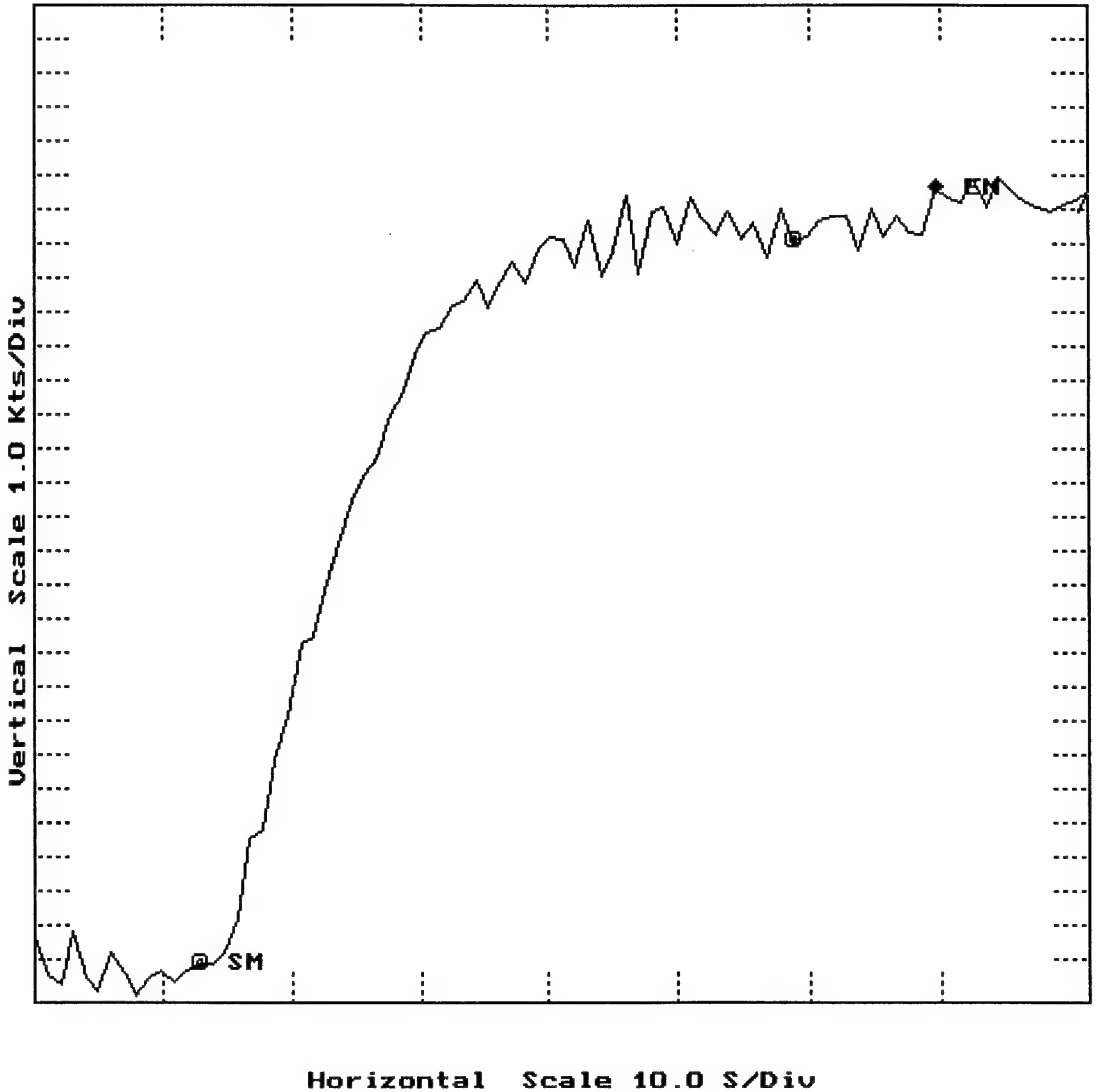
26 September 1995
23:21:06
Acceleration
Maneuver # 7
0 Rudder

Velocity Plt
Plot Center:
38 54.8 N
74 47.7 W



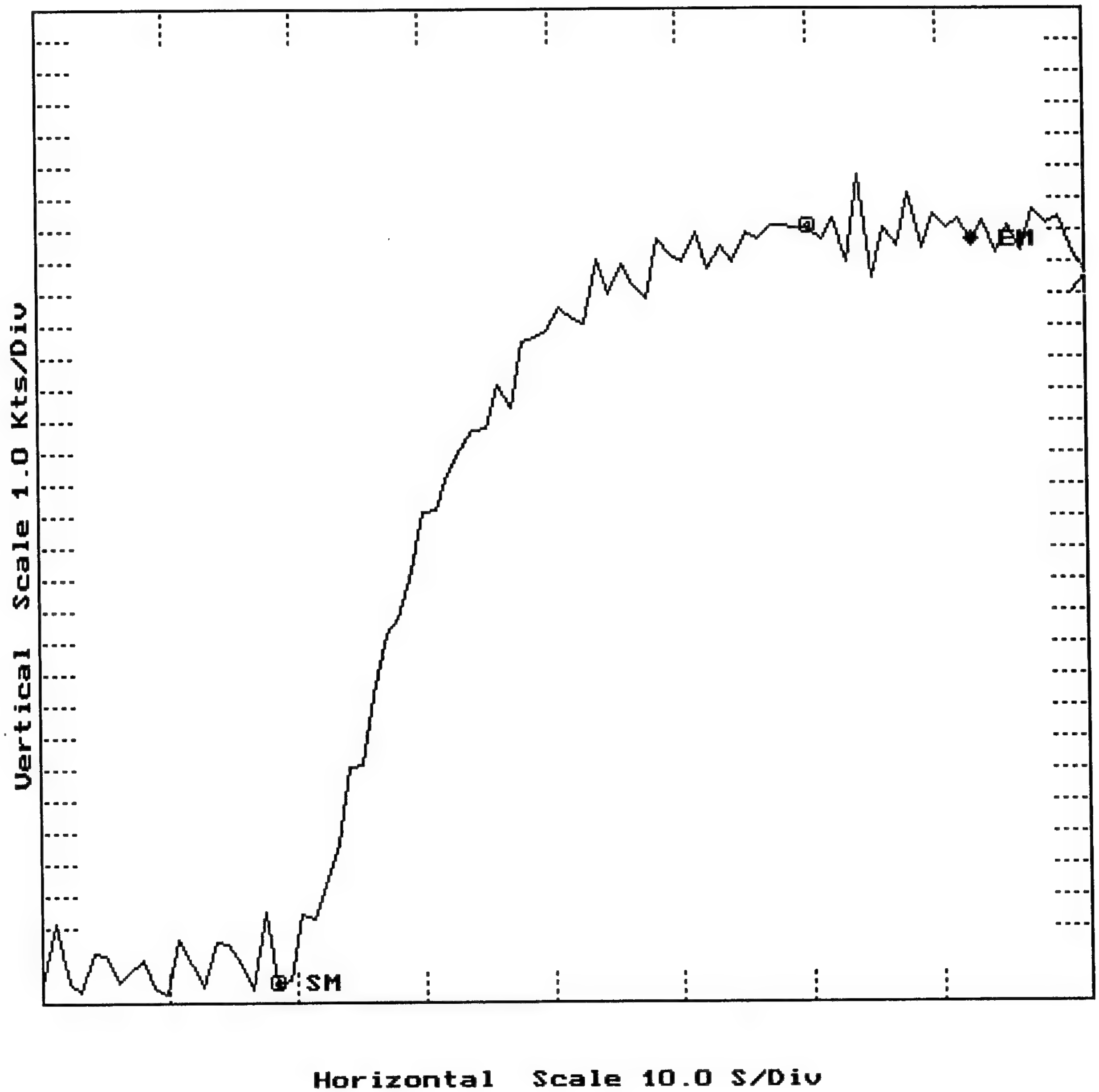
26 September 1995
23:23:57
Acceleration
Maneuver # 8
0 Rudder

Velocity Plt
Plot Center:
38 54.4 N
74 47.9 W



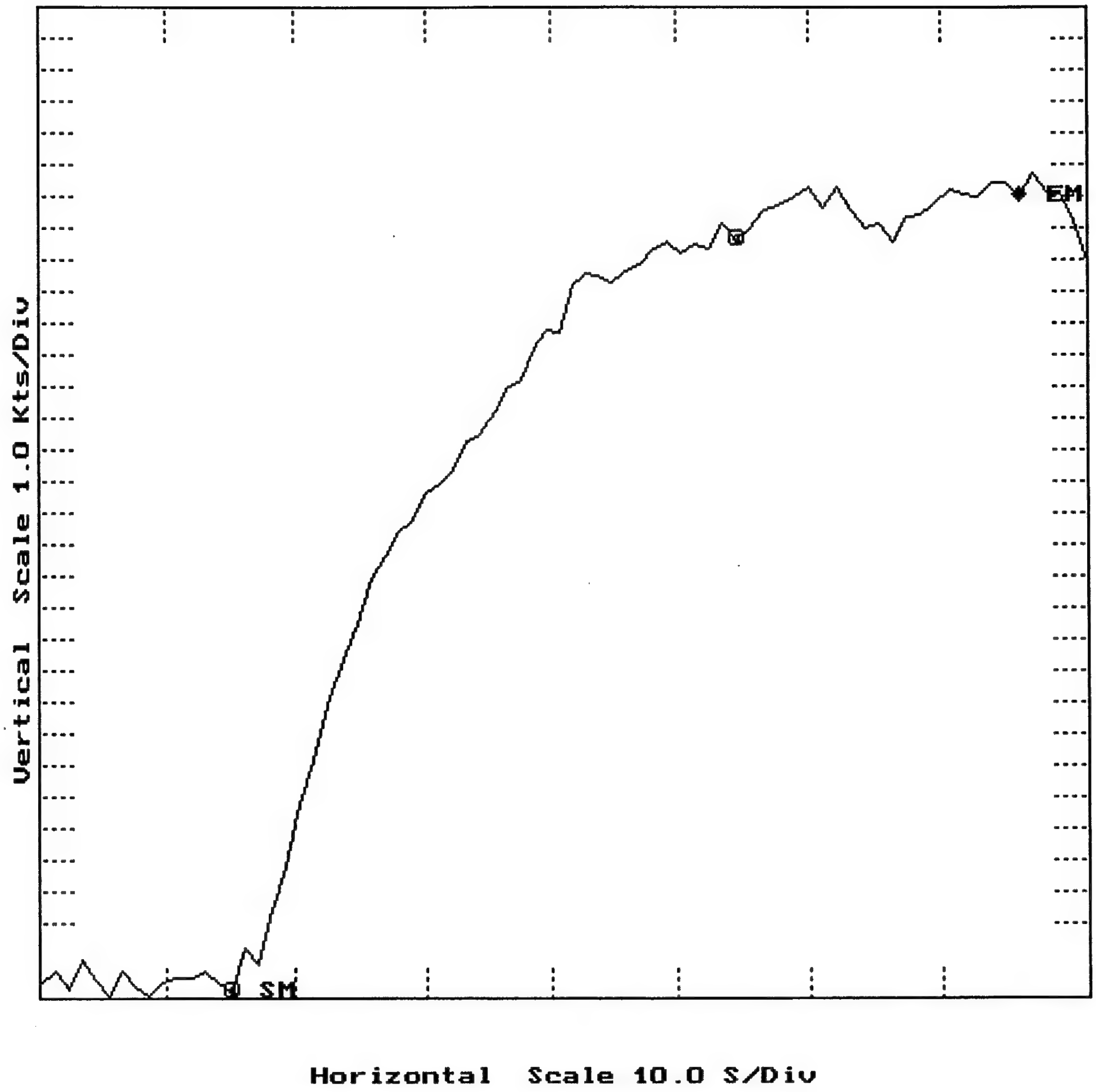
26 September 1995
23:26:47
Acceleration
Maneuver # 9
0 Rudder

Velocity Plt
Plot Center:
38 54.8 N
74 47.6 W



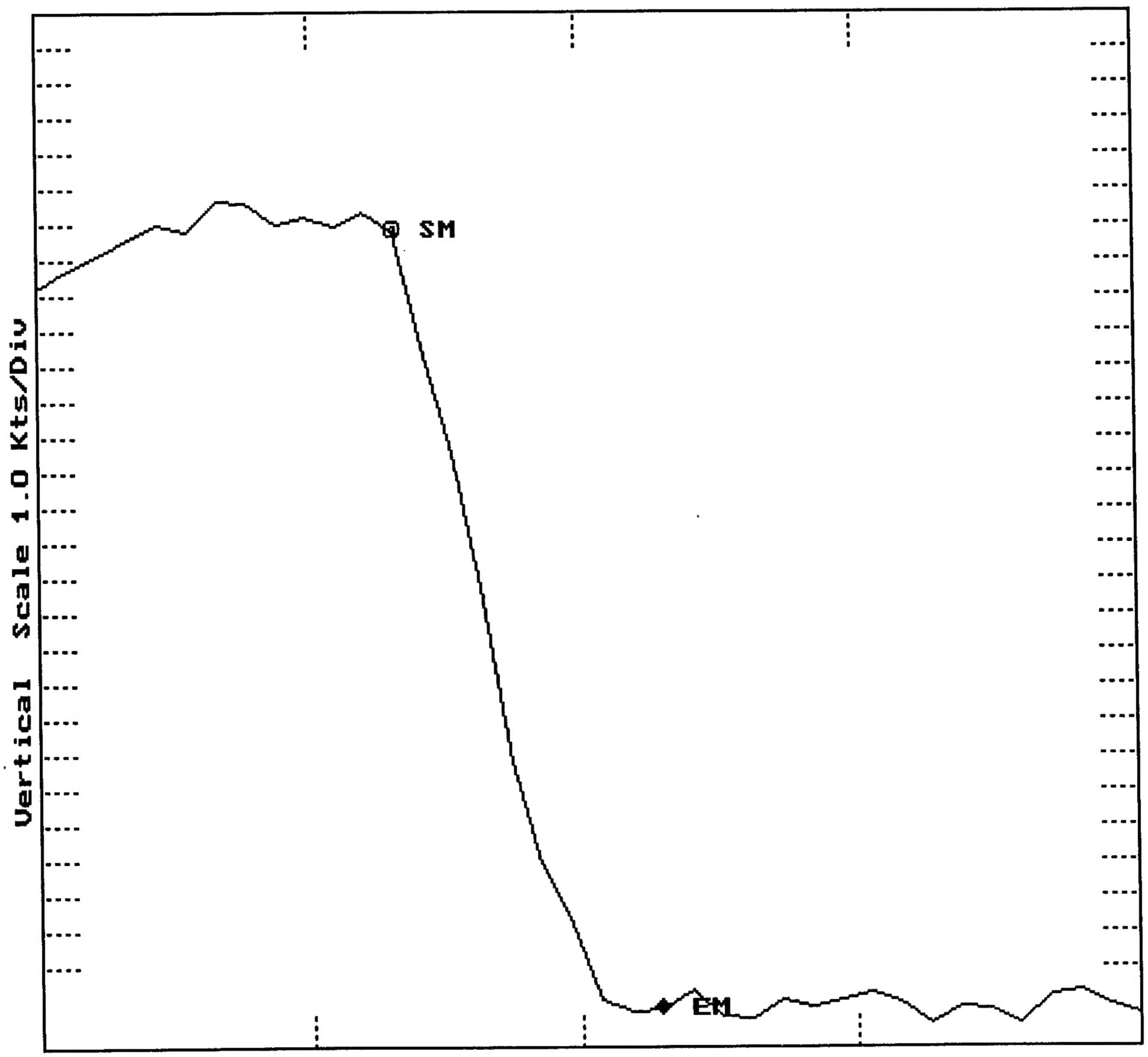
26 September 1995
23:29:13
Acceleration
Maneuver # 10
0 Rudder

Velocity Plt
Plot Center:
38 55.1 N
74 47.5 W



26 September 1995
23:33:07
Deceleration
Maneuver # 11
0 Rudder

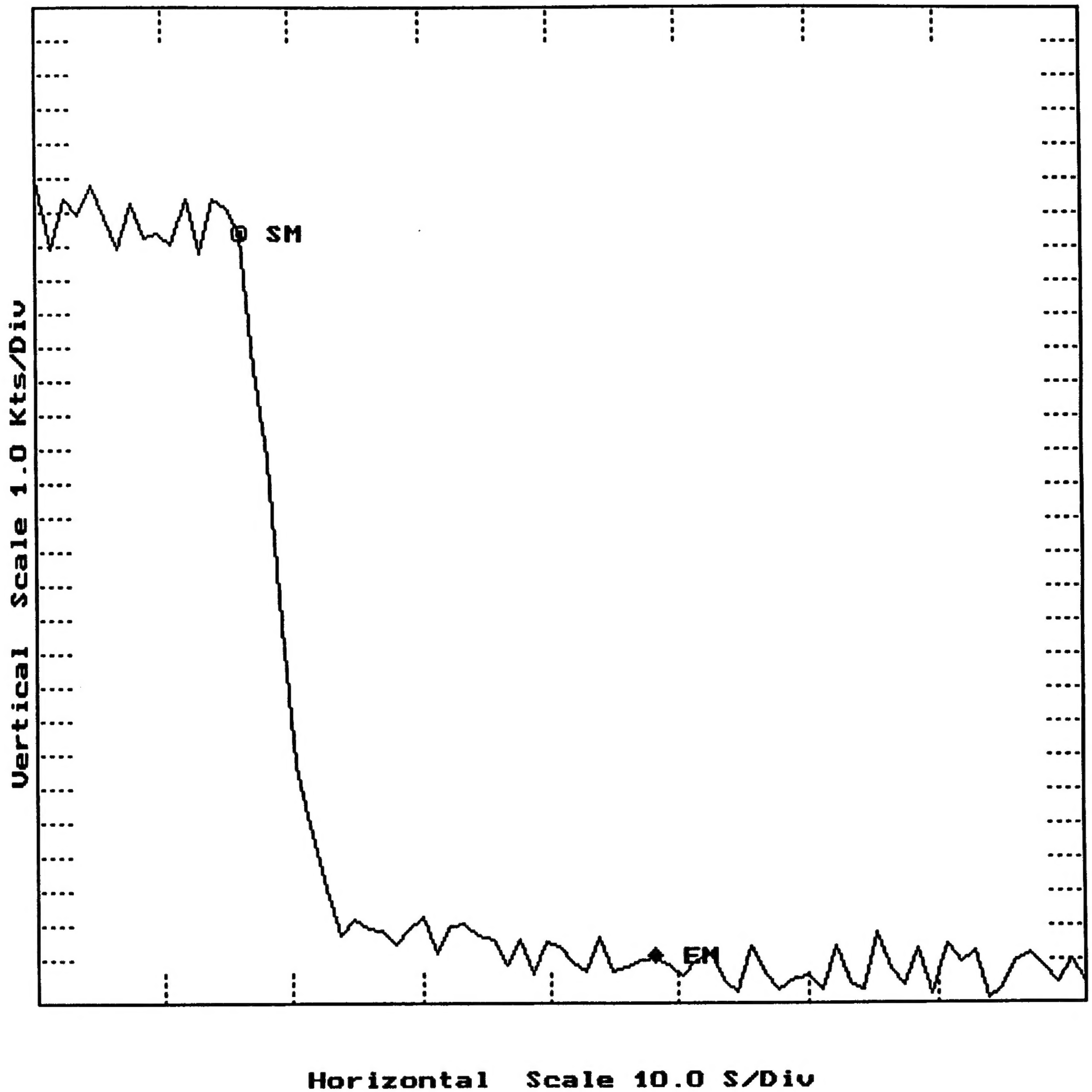
Velocity Plt
Plot Center:
38 54.5 N
74 47.6 W



Horizontal Scale 10.0 S/Div

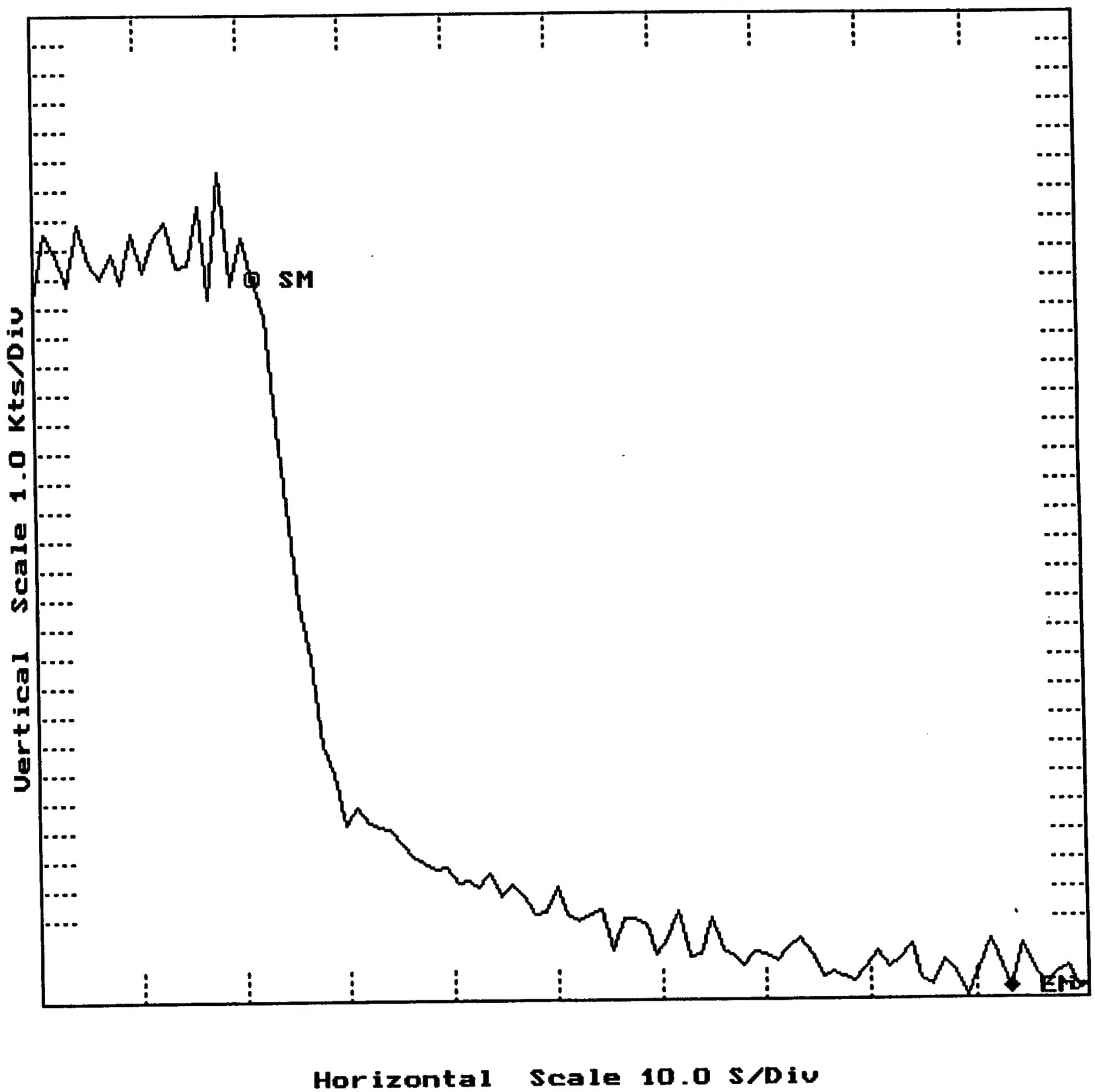
26 September 1995
23:35:51
Deceleration
Maneuver # 12
0 Rudder

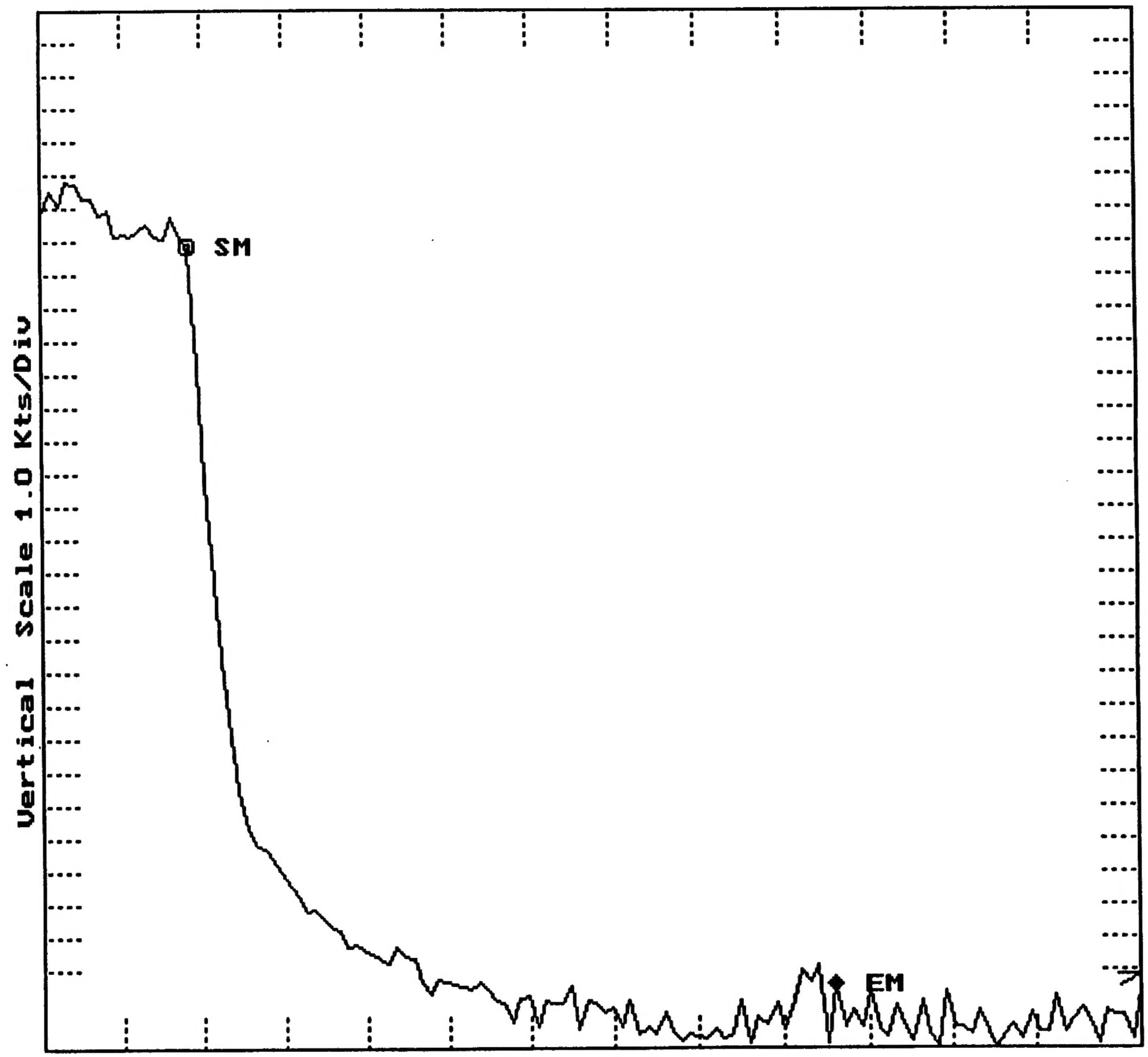
Velocity Plt
Plot Center:
38 54.6 N
74 47.5 W



26 September 1995
23:38:20
Deceleration
Maneuver # 13
0 Rudder

Velocity Plt
Plot Center:
38 55.0 N
74 47.4 W





26 September 1995
23:41:30
Deceleration
Maneuver # 14
0 Rudder

Velocity Plt
Plot Center:
38 54.8 N
74 47.4 W